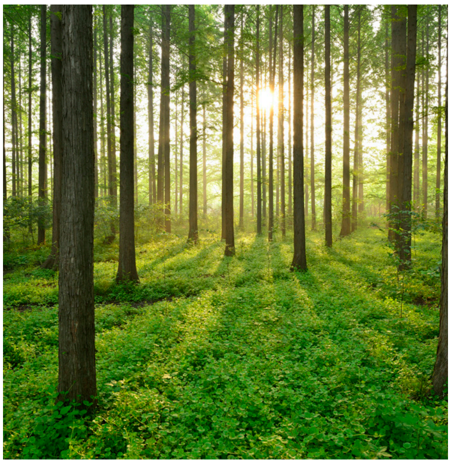
REFERENCE MILL FOR BLEACHED KRAFTMARKET PULP 2024

REPORT 2025:1095



SKOGSINDUSTRIELLA PROGRAMMET

Energiforsk

Reference mill for bleached kraft market pulp 2024

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Foreword

There is great value in developing reference mills to show how energy-efficient new mills can be built based on current technologies. The pulp and paper industry has a central role in the transition to greater use of sustainable materials and renewable energy. It is in the interest of both industry and society that production takes place in the most resource-efficient way possible. The ability to compare their processes with the best available technology is important to drive development, Previously developed model and reference factories have facilitated the possibilities to systematically evaluate the integration of new process concepts with existing processes.

The main objective of the project has been to define, in a well-established process, updated reference mills with detailed overall material and energy balances that can be used, for example, to show how energy-efficient mills can be built using existing and proven technology and to highlight the potential for energy savings in the industry. The project's goal has also been to show the potential for extracting energy from the pulp and paper industry with existing production.

The project has resulted in two reports, 2025-1095 Reference Mill for Bleached kraft market pulp and 2025-1096 Reference Mill for Integrated Cartonboard.

Stockholm i March 2025

Marie Kofod-Hansen

Ansvarig för Skogsindustriella programmet

These are the results and conclusions of a project, which is part of a research programme run by Energiforsk. The author/authors are responsible for the content.

Summary

The purpose of this study was to update hypothetical "reference mills", representing the state-of-the-art of pulp and paper production in the Nordic countries. These model mills have been developed in several versions going back all the way to the 1970s. The main emphasis has been on solutions which have affected energy use and electricity production. The reference mills have typically been used for benchmarking and for evaluating new process concepts in relation to the reference concept.

Two different types of pulp and paper mills were considered:

- Bleached kraft market pulp – one softwood mill and one hardwood mill
- Integrated cartonboard mill, with the pulp mill producing softwood and hardwood pulp in campaigns

This report describes the mills that produce dried and bleached kraft pulp to be sold on the market. A separate report describes the integrated cartonboard mill.

Each mill is in this report considered as a single line mill with a maximum continuous rate (MCR) of 4000 ADt/d (air-dry tons of pulp per day). Configurations are based on AFRY's experience with existing mills and input from the major mill equipment suppliers. Mass and energy balances have been calculated using spreadsheet models developed by AFRY.

The process steam consumption in the *softwood reference mill* is about 8.4 GJ/ADt. Heat generated from black liquor and falling bark amounts to about 20 GJ/ADt (880 MW) and there is thus a large excess of steam that is used for electricity generation.

Approximately two thirds of the generated steam pass the back-pressure turbine to produce 155 MW of electric power. The remaining steam is fed to the condensing turbine, which generates a similar amount of electric power, ca 138 MW. Power consumption in the process is ca 98 MW. There is thus a potential to sell as much as 195 MW, corresponding to more than 1.15 MWh/ADt.

Process steam consumption in the *birch reference mill* is slightly lower, ca 8.1 GJ/ADt, mainly because the pulp yield is higher than for softwood, resulting in less black liquor and a smaller evaporation demand.

Because of the smaller amount of black liquor to the recovery boiler in the birch mill, the amount of steam generated is about 15% smaller. The total steam generation in the mill is compensated by the fact that there is more bark available in the birch mill. This is an indirect effect of the use of saw mill chips as part of the feedstock in the softwood mill, giving less falling bark in that case. Power consumption in the birch mill is ca 93 MW. There is a potential to sell 182 MW, corresponding to ca 1.1 MWh/ADt.

Keywords

Kraft pulp, steam, power, energy, model

Sammanfattning

Syftet med denna studie var att uppdatera hypotetiska "referensfabriker" som motsvarar modern massa- och pappersproduktion i de nordiska länderna. Dessa modellfabriker har utvecklats i flera versioner ända sedan 1970-talet. Tyngdpunkten har legat på faktorer som påverkar energianvändning och elproduktion. Referensfabrikerna har använts för benchmarking och för att utvärdera nya processkoncept i förhållande till grundkonceptet.

Två olika typer av massa- och pappersbruk inkluderades:

- Fabriker för blekt avsalumassa – från barrved respektive lövved
- Integrerad kartongfabrik, där massabruket producerar barr- och lövvedsmassa i kampanjer

I denna rapport beskrivs de bruk som producerar torkad och blekt sulfatmassa för avsalu. En separat rapport beskriver den integrerade kartongfabriken.

Varje fabrik behandlas i denna rapport som en enkel fiberlinje med en maximal kontinuerlig produktionskapacitet på 4000 ADt/d (ton lufttorr massa per dygn). Konfigurationerna är baserade på AFRYs erfarenhet av befintliga bruk och input från leverantörerna av utrustning. Mass- och energibalanser har beräknats med hjälp av kalkylbladsmodeller utvecklade av AFRY.

Förbrukningen av processånga i *referensfabriken för barrved* är cirka 8,4 GJ/ADt. Värmeproduktionen från svartlut och fallande bark uppgår till cirka 20 GJ/ADt (880MW) och det finns därmed ett stort överskott av ånga som används för elproduktion.

Ungefär två tredjedelar av den genererade ångan passerar mottrycksturbinen och producerar 155 MW el. Den återstående ångan matas till en kondensturbin som genererar ungefär lika mycket el, ca 138 MW. Effektförbrukningen i processen är ca 98 MW. Det finns därmed en potential att sälja så mycket som 195 MW, motsvarande mer än 1,15 MWh/ADt.

Förbrukningen av processånga i *referensfabriken för björk* är något lägre, ca 8,1 GJ/ADt, främst på grund av att massautbytet är högre än för barrved, vilket resulterar i mindre svartlut och ett mindre indunstningsbehov.

På grund av den mindre mängden svartlut till sodapannan i björkfabriken är mängden ånga som genereras ca 15 % mindre än i barrvedsfabriken. Den totala ångproduktionen kompenseras dock av att det finns mer bark att tillgå i björkfabriken. Detta är en indirekt effekt av användningen av sågverksflis som en del av råvaran i barrvedsbruket, vilket i det fallet ger en mindre mängd fallande bark. Elförbrukningen i björkfabriken är ca 93 MW. Det finns potential att sälja 182 MW, motsvarande ca 1,1 MWh/ADt.

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1 Introduction

1.1 SCOPE AND PURPOSE

The purpose of this study financed by Energiforsk was to update the hypothetical reference mills, which have been developed in several versions, going back all the way to the 1970s [1-4]. Revisions have been done with intervals of 5-15 years to reflect the technical changes that have occurred in recent years. The most recent update was done in 2010.

The main emphasis has been on changes which have affected energy use and electricity production. The reference mills have typically been used for benchmarking and in many other studies for evaluating new process concepts in relation to the "standard" concept.

Two different types of pulp and paper mills were considered:

- Bleached market kraft pulp mills – one softwood mill and one hardwood mill
- Integrated cartonboard mill, with the pulp mill producing softwood and hardwood pulp in campaigns

Modifications made in this study are based on AFRY's experience with existing mills, and in some cases data from the major mill equipment suppliers. Material and energy balances have been calculated for the 2024 reference mills using spreadsheet models developed by AFRY.

The market pulp mills and the integrated pulp and paper mill are described in separate reports, although much of the information on the pulp mill is the same for both. This report describes the market pulp mills.

1.2 BRIEF HISTORY OF THE REFERENCE MILLS

The first versions of the reference or "model" mills were created in response to the first oil crisis in 1973, when SCPF (now Skogsindustrierna) commissioned ÅF (now AFRY) to carry out an investigation into how energy-efficient a mill could be built using the best available technology. Four main types of mills were included: linerboard, tissue paper, bleached market pulp and newsprint. The model mills were assumed to be newly built with the most modern technology already in operation, or that could be purchased with customary supplier guarantees, and able to meet the environmental limits.

Towards the end of the 1980s, updated versions were prepared by ÅF in a project co-financed by STU [1], and again in the late 1990s within the "Eco-Cyclic Pulp Mill Program" co-financed by MISTRA [2]. The most recent revisions were done jointly by STFI and ÅF in the 2004 FRAM (Future Resource-Adapted Mill) project co-funded by the Swedish Energy Agency [3], and in a 2010 study co-funded by ÅForsk and the Swedish Energy Agency [4, 5]. All projects have been co-funded by forest industry companies, which have usually been very active in discussions and definitions. The hypothetical mills have been referred to as "model mills", "ideal mills" and "reference mills" in different studies but have always been developed with the same general approach as the first versions. This report thus continues a 50-year long tradition of summarizing energy balances for state-of-the-art pulp mills.

2 Reference mills - overview

2.1 GENERAL DESIGN CRITERIA

Two different feedstocks were considered for the reference mills producing bleached kraft pulp:

- softwood (pine/spruce)
- hardwood (birch)

The design of each reference mill is based on best available and commercially proven technology. The mill configurations largely represent solutions used in the Nordic countries.

The design of each of the mills considers:

- high, consistent pulp quality which is competitive on the international market
- the product is elemental chlorine free (ECF)
- low specific consumptions of wood, chemicals, and water
- high energy efficiency
- maximized production of bio-energy, and minimal usage of fossil fuels
- low environmental emissions; on the level of newer modern mills
- cost-effective solutions

Different suppliers offer process equipment of various types. The reference mills are not based on equipment from any one supplier. In general, the key process data used in the balances in this study are conservative and should not exclude any of the major pulp mill equipment suppliers.

2.2 MILL PRODUCTION AND CAPACITY

Mill production capacity in the industry varies widely from older mills producing less than 1000 ADt/d to newer single line mills which operate at >4000 ADt/d.

Campaign operation of softwood and hardwood pulp is common in many mills. In terms of mill capacity the main difference between hardwood and softwood is that hardwood has a higher yield. This means that the black liquor dry solids per ton of pulp is higher for softwood than for hardwood, and consequently the required capacity of the chemical recovery line is greater for a softwood mill compared to a hardwood mill with the same pulp production capacity. Campaign production of softwood and hardwood maximizes utilization of the recovery boiler, and the total capital cost for the combined production is minimized. There are also some advantages in terms of the millwide energy and chemical balances with campaign operation.

For clarity, however, each mill is in this report considered as a single line mill with a maximum continuous rate (MCR) of 4000 ADt/d.

Mass balances have been prepared for the reference mills for mill MCR conditions to determine the capacity requirements for the main mill areas. The balances cover, e.g., wood, chemicals, black liquor dry solids and lime. Elemental mass balances have also been done for sodium and sulfur. Table 2-1 summarizes the key operating and dimensioning data for the reference mills.

Table 2-1. Summary of pulp mill key operating data.

		Softwood	Birch
Dried pulp from dryer	ADt/d	4 000	4 000
Operating days	d/a	355	355
Mill availability	%	92	92
Annual production	ADt/a	1 306 400	1 306 400
Wood yard			
Roundwood with bark/Saw mill chips	%	70/30	100/0
Wood to digester	tDS/d	8145	7376
Bark and wood waste	tDS/d	799	990
Digester Plant			
Kappa number		30	17
Unscreened deknotted digester yield	%	47.0	51.0
Alkali charge on wood as effective alkali	NaOH,%	20.0	18.5
Sulfidity (white liquor)	mole-%	38	38
Oxygen Stage			
Kappa number after oxygen stage		12	11
Alkali charge as NaOH	kg/ADt	30	18
Oxygen charge	kg/ADt	20	14
Washing Department			
Dilution factor in the last stage	m^3/ADt unbl.	2.5	2.5
Evaporation Plant			
Weak black liquor to evaporation, excl.spill	t/h	1846	1578
ditto dry solids content	%	16.0	15.6
Strong black liquor, dry solids content incl. ash	%	83	83
Total evaporation, including spill	t/h	1571	1364
Recovery Boiler			
Estimated higher heating value of virgin DS	MJ/kg	13.9	13.9
Strong liquor virgin solids to mixing tank	t/24 h	7061	5869
Net useful heat from liquor, virgin solids	MJ/kg DS	9.9	10.1
Net useful heat from liquor	MW	806	685
Causticizing and Lime Kiln			
Causticizing efficiency	mole-%	82	82
Total white liquor production	m^3/24 h	15749	12762
Lime kiln load (as lime product)	t/24 h	1063	862
Active CaO in lime	%	90	90

2.3 ENERGY SYSTEMS AND BALANCES

The reference mills are designed to be energy efficient. The mills would be self-sufficient in both power and steam with only the recovery boiler and back pressure turbine. The mills have a power boiler to make use of surplus bark and wood waste, and for sludge recovery. There is an excess of steam from the recovery and power boilers which is utilized in a condensing turbine to produce renewable power for export.

The lime kiln is fired with gasified bark, and the remaining bark from the woodyard and chip screening is co-fired with sludges from effluent treatment in the power boiler.

Table 2-2. Summary of steam and power balances for the 2024 reference mills.

	SW	Birch
STEAM BALANCE (GJ/ADt)		
Generation		
Recovery boiler	17.41	14.80
Power boiler	1.61	3.14
H_2SO_4 heat recovery	0.11	0.00
Secondary heat	0.85	0.81
Total steam generation	19.97	18.75
Consumption		
Process steam	8.45	8.12
Back pressure turbine	3.48	3.36
Condensing turbine	8.04	7.28
Total steam consumption	19.97	18.75
POWER BALANCE (kWh/ADt)		
Generation		
Back pressure power	932	900
Condensing power	828	750
Total power generation	1 759	1 650
Consumption		
Mill consumption	590	560
Sold power	1 169	1 090
Total power consumption	1 759	1 650

The difference in power boiler capacity between the birch mill and the softwood mill is mainly a result of selected wood supply, 100% roundwood for birch and 70% for softwood. It also accounts for differences in heating values and the amount of falling bark that is gasified to be used as fuel in the lime kiln.

3 Process Description

3.1 WOOD SUPPLY

The softwood raw material consists of 50% pine (*Pinus sylvestris*) and 50% spruce (*Picea abies*). The relation between roundwood with bark and sawmill chips is 70% roundwood and 30% sawmill chips.

The birch is mainly *Betula spp.* with about 10% other hardwoods, mainly aspen. The supply is 100% as roundwood, with bark.

3.2 WOODYARD

The softwood and birch debarking is performed in dry debarking drums which are designed for a barking efficiency of 95%. There is a closed re-circulation of sprinkling and de-icing water. The de-icing water is heated by the means of heat exchanging with surplus hot water. The effluent is collected together with the press water from the bark presses in a sedimentation basin for re-circulation. The sludge from the sedimentation basin is burned in the power boiler.

A portion of the bark is utilized as fuel for the lime kiln; the rest is burned in the power boiler.

After debarking the logs are transported to a metal detector and a water stone trap. In the chipper, logs are cut to chips. Consistent chip thickness is important for uniform cooking and a low pins fraction is important for the runnability of the digester. The chips are therefore screened to get an optimal chip size. Accepted chips are transported to a chip silo. Over-thick, over-sized chips are taken to a re-chipper and then back to chip screening. Fines, about 0,5% of the chipped wood, are stored and burned in the power boiler.

3.3 DIGESTER

Either continuous or batch digesting can be used, and both alternatives have pros and cons. Continuous digesters are the dominant technology for both existing and new mills. Also, in general the batch processes, as marketed today have higher steam consumption than the continuous processes. Thus, the continuous cooking process has been selected for this study.

The Valmet Continuous Cooking concept, see Figure 1, is one example of a modern cooking system. Chips are pre-steamed and impregnated with white liquor and black liquor at atmospheric conditions in a vessel, and the cooking is performed at a relatively high alkalinity with co-current liquor flow at relatively low temperature. The cooking temperature is about 155°C for softwood, and 145°C for birch. Black liquor is extracted for evaporation from the impregnation vessel via liquor filters and is pumped to the evaporation plant.

Andritz DownFlow LoSolids cooking system with or without a pressurized impregnation vessel is another example of a modern cooking system.

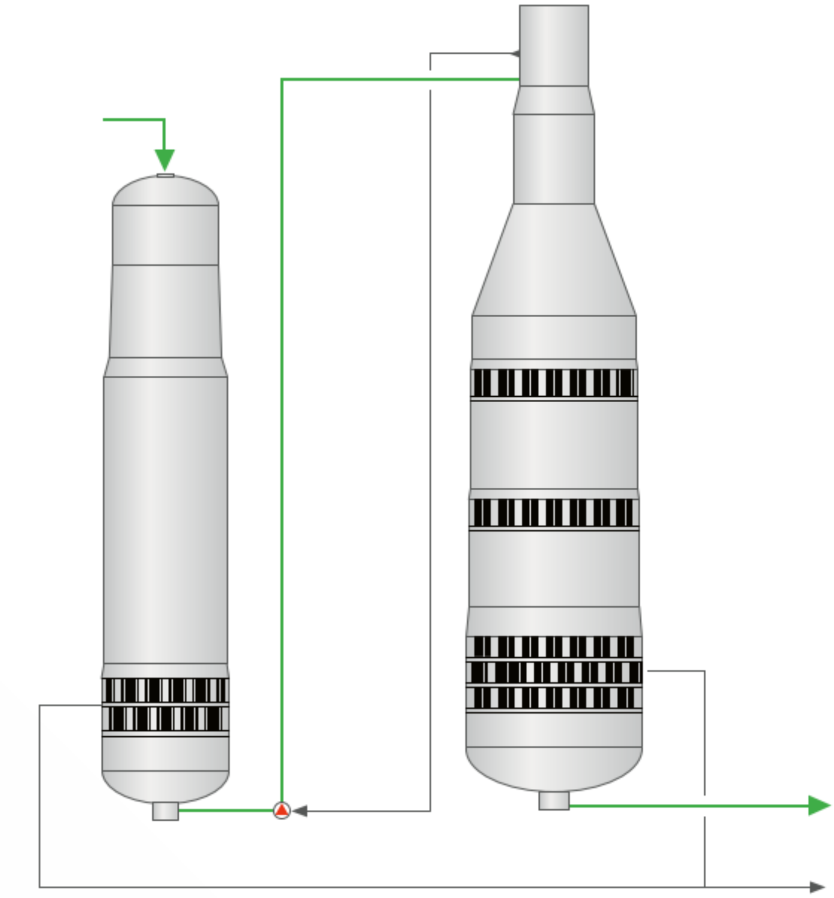

Figure 1. Example continuous cooking system (Valmet Continuous Cooking).

Table 3-1. Digester key figures.

		SW	Birch
Kappa number, digester blowline		30-32	17-18
Deknotted digester yield	%	47	51
White liquor AA concentration	NaOH, g/l	140	140
Alkali charge on wood as effective alkali	NaOH, %	20.0	18.5
Sulfidity, white liquor	%	38	38
Extracted turpentine	kg/ADt	2	0

In order to improve yield and fiber strength the kappa number after cooking could be increased by some units. This should however be balanced with the delignification in the oxygen stage.

3.4 BROWNSTOCK DEKNOTTING AND SCREENING

There are several important quality parameters for pulp. One of them is very high cleanliness, i.e. a low content of shives and colored spots originating from the pulpwood (resin and bark) as well as foreign materials such as sand, plastic, rubber and rust.

Pressurized deknotting separates knots from the pulp. After deknotting the pulp is screened at 3-4% consistency by barrier (slotted) screens in three or four stages. The knots are recooked. Screen rejects from the last screening stage can be refined and be returned to the process or taken to a screw press to be dewatered to about 30-40% consistency prior to a dumpster. The rejects from the dumpster are burned in the power boiler.

3.5 OXYGEN DELIGNIFICATION

Oxygen delignification is done in two stages without intermediate washing to a kappa number of 11-12 for softwood and 10-11 for birch. Oxidized white liquor is the primary alkali source. To optimize the delignification in the initial and final phases the reaction time is approximately 10-30 minutes in the 1st stage and approximately 60 minutes in the 2nd stage.

Table 3-2. Oxygen delignification key figures.

		SW	Birch
Kappa number after oxygen stage		11-12	10-11
Dissolved DS (yield losses)	%	3.8	1.6
MgSO4 charge		1-2	0-1
Alkali charge oxidized WL, as NaOH	kg/ADt O2	28-32	18
Oxygen charge	kg/ADt O2	20-22	14
Temperature first stage	^{o}C	90 - 95	90 - 95
Temperature second stage	^{o}C	95 - 100	95 - 100

3.6 PULP WASHING

The brown stock washing consists of:

- Two or three stages for softwood and birch. Either wash presses or drum displacement (DD) filters can be used.
- Post oxygen washing with one 2-stage DD washer before the oxygen bleached storage tower. Alternatively, two wash presses could be used. These wash presses may be placed after the oxygen blow tank (and before the unbleached storage tower) or, one of the presses could be located before the unbleached storage tower and one after (pre bleach press).

Figure 2 shows one alternative for brownstock washing.

The brownstock washing dilution factor is 2.5 m^3/ADt.

The carryover of TOC from the oxygen delignification to the bleach plant is calculated to be approximately 3 kg TOC/ADt (corresponding to about 8-9 kg/ADt COD), excluding the TOC in bleach plant filtrate re-circulated to brown stock washing.

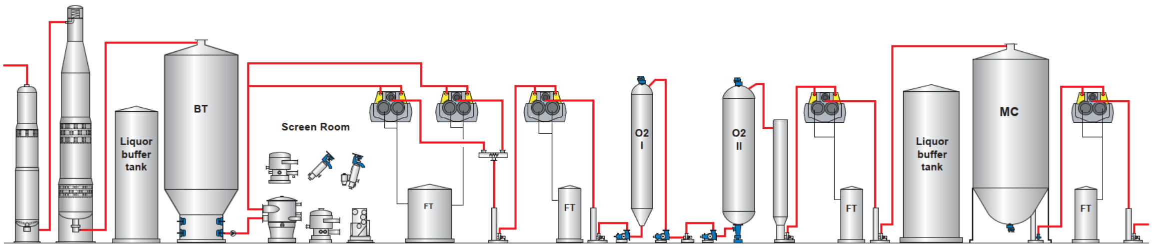

Figure 2. One example of a typical brownstock washing system (Valmet).

3.7 BLEACHING

The softwood and birch pulps are bleached to a final brightness of 90%.

The bleach plant is designed with three or four bleaching stages. For softwood pulp the first stage is operated as a "conventional" D-stage, and the sequence is D(EOP)DP. For birch pulp the first stage is operated as a D_{hot}-stage, and the sequence is D_{hot}(EOP)DP.

Wash presses or 1-stage DD washers are used for all washing in the bleach plant.

The main reason for selecting a hot first D stage for birch pulp is that a lower charge of ClO_2 is required to attain the required pulp brightness, and that less brightness reversion of the fully bleached pulp takes place. These benefits are, however, not attained on softwood pulps as they contain considerably less hexenuronic acids than birch pulp. Hexenuronic acids are effectively removed in D_{hot}-stages.

The last bleaching stage could be a D-stage instead of a P-stage. This is partly an economic decision which depends on the prices of chlorine dioxide, hydrogen peroxide and sodium hydroxide. A final P-stage in place of a final D-stage may also decrease brightness reversion.

The expected bleach plant chemical charges and conditions are summarized in Table 3-3 and Table 3-4.

For softwood the bleaching sequence results in a yield of 98%, which corresponds to a total yield of about 44% (including losses in cooking and oxygen delignification). For birch pulp the bleaching sequence results in a yield of about 97.5% and a total yield of about 49% for birch.

Table 3-3. Expected chemical charges for the SW kraft pulp with the sequence D(EOP)DP to 90%ISO brightness (kg/ADt). ClO_2 as ClO_2 and not as active Cl. Kappa number of pulp to bleaching: 12.

Stage	Temp (°C)	Time (min)	pH	ClO_2	O_2	H_2O_2	NaOH	H_2SO_4	$NaHSO_3$
D	70	30-40	~2,5	9				4	
(EOP)	80-85	75-90	10.5-11		6	1	13		
D	75-80	120	3.5-4	5			1		0.5
P	75-80	120	~10			6	6	1.5 (a)	

(a) After P-stage

Table 3-4. Expected chemical charges for the birch kraft pulp with the sequence D_{hot}(EOP)DP to 90%ISO brightness (kg/ADt). ClO_2 as ClO_2 and not as active Cl. Kappa number of pulp to bleaching: 10.

Stage	Temp (°C)	Time (min)	pH	ClO_2	O_2	H_2O_2	NaOH	H_2SO_4	$NaHSO_3$
D_{hot}	85-90	120	~3	7				6	
(EOP)	85-90	60	10.5-11		3	1	12		
D	75-80	120	3.5-4	5			1		0.5
P	75-80	120	~10			6	6	1.5 (a)	

(a) After P-stage

3.8 SYSTEM CLOSURE AND HANDLING OF NA/S BALANCES

3.8.1 Degree of bleach plant filtrate recovery

A high degree of system closure can create problems with scale formation within the bleach and evaporation plants, high bleaching chemical consumption, corrosion and plugging problems in the recovery boiler and problems controlling the Na/S balance of the mill. Bleach plant liquors must be handled in an optimal manner; for example, mixing should be performed within critical temperature and pH limits, where the risk for scaling is the lowest.

Based on experience a relatively conservative approach regarding system closure has been adopted to ensure sustained trouble-free operation with good economics.

The bleach plant is designed to release 8-15 t/ADt of effluent. This range includes an allowance for up to 5 t/ADt of fresh water. This extra intake of fresh water can be used for washing or dilution at any position in the bleach plant where there is a risk for precipitation. The extra intake of fresh water also makes it possible to bleed out metals and Cl^--ions.

Figure 3 shows the approximate liquor flows in the bleach plant for a D(EOP)DP bleaching sequence. White water from the pulp machine is used as dilution after the final bleaching stage washer and as wash liquor on the wash press after the final P-stage. The filtrate from this wash press is then used as wash liquor on the EOP-stage wash press. Hot water is used as wash liquor on the D1-stage wash press and condensate is used as wash liquor on the D0-stage press. The filtrate from the (EOP) wash press is then transferred as wash liquor to the 2nd wash press after the oxygen stage.

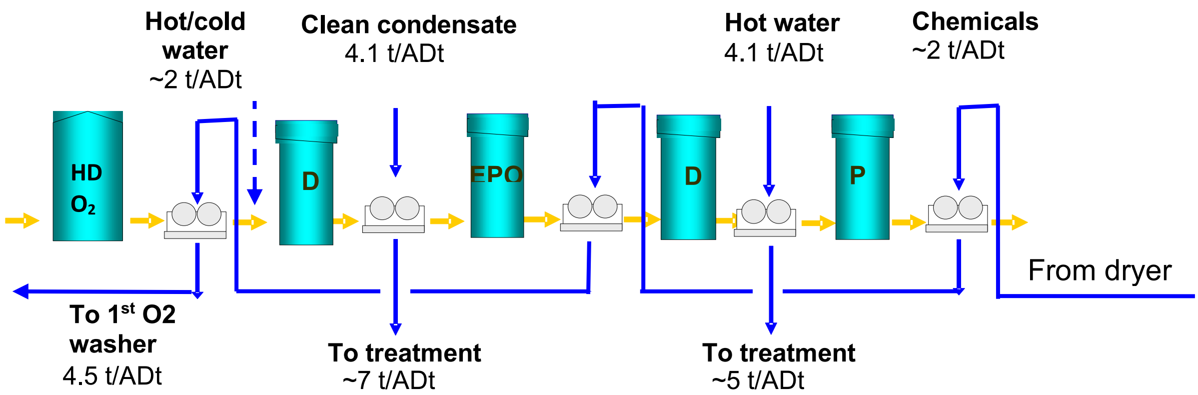

Figure 3. The approximate liquor flows (t/ADt) of the ECF bleach plant. The dilution factor is about 2 t/ADt.

3.8.2 Sodium-sulfur balance and chemicals supply

The reference mills include features that affect the sodium and sulfur balances and reduce the sodium make-up demand:

Filtrate recycle from the EOP bleaching stage to the brownstock washing

A sulfuric acid plant to internally generate all sulfuric acid needed for chlorine dioxide generation and tall oil acidulation

The effect of these features is to almost eliminate all direct sodium make-up intake as the sodium intake to the recovery cycle through EOP stage filtrate and chlorine dioxide plant by-product is more than needed to cover the soda losses of the mill.

One effect of the recycle of EOP and P stage effluents is that the mill bleach plant effluent will be significantly more acidic with an increased neutralization demand. To utilize the excess sodium available, oxidized white liquor is used for effluent neutralization. This also removes substantial amounts of chloride and potassium from the recovery cycle. Consequently, the capacity of the chloride removal process (CRP) can be minimized.

To maintain the sulfur balance, an intake of elemental sulfur to the sulfuric acid plant furnace is assumed. This elemental sulfur will then also act as support fuel allowing all by-product methanol to be used for other purposes.

The overall sodium-sulfur balance for the softwood mill is shown in Appendix A and B.

Other configurations aimed at totally eliminating external caustic soda intake to the recovery loop as well as the bleach plant are possible but not considered widely accepted technology today.

3.9 PULP DRYING

3.9.1 Secondary screening, wet end and press section

The secondary screening plant included in the stock preparation is a pressure screen concept with slotted screen baskets in a cascade arrangement. The consistency is between 1.5 – 3.5 % Secondary screening can either be between blend chest and machine chest or in short circulation. Last 2 or 3 recovery stages of secondary screening plant are with centrifugal cleaners. Pressure screens have proven to be able to produce pulp with a good cleanliness with low energy consumption. The screened pulp is diluted in the approach flow system to 1 – 2 % consistency and fed to the hydraulic headbox. Typical system temperature in short circulation is about 65°C without any addition of steam. For optimum CD basis weight profile the headbox is equipped with an automatic CD dilution control system.

For efficient dewatering and short forming section length, either a twin wire configuration or a hybrid former which is a fourdrinier with a top wire is considered. At the end of forming section a steam box or hot water boxes are used for heating of sheet which improves dewatering in press section.

For efficient dewatering a combi-press followed by one or two double felted shoe presses is considered. In the first open draw, after the 2nd nip of combi press, the sheet has a dryness of above 40 %. The shoe press gives a dryness into the dryer of 50 - 54 % for pine and birch depending on specific production and number of shoe presses.

3.9.2 Dryer and heat recovery

The pulp dryer is of floating web type, which dries the pulp web while keeping it floating on a cushion of hot air heated by LP (3 - 3.5 bar(g)) steam. One or two bottom decks are used to cool the dried pulp web to about 40 - 45 °C. Cooling reduces the brightness reversion of the pulp during storage and transportation.

Exhaust air from the pulp dryer goes through the heat recovery system where supply air to dryer, shower water and machine hall supply air are heated with energy in exhaust air. Also, dryer blow though steam and condensate are used for dryer supply air pre-heating.

3.9.3 Cutter-layboy and baling

The cutter-layboy handles the dry web from the pulp dryer. As the web passes through the slitting and cutting section it is slit and cut into bale size or wrapper size sheets. The sheets are conveyed to the layboy where they are formed into stacks on the layboy conveyor.

Three complete baling lines are required for a production of 4000 ADt/d. Bales are wrapped with pulp sheet or kraft paper and tied to an 8-bale shipping unit with a weight of 2 tons.

3.10 CHLORINE DIOXIDE GENERATION

The selection of the chlorine dioxide process (R8 or R10) is mainly based on the millwide sodium/sulfur balance. (R8 and R10 are the trade names from Erco. Nouryon has similar processes called SVP and SVP-SCW respectively.)

In both the R8 and R10 processes purchased sodium chlorate reacts with sulfuric acid, with methanol as the reducing agent, to produce chlorine dioxide and the by-product $Na_3H(SO_4)_2$. The R10 process however has an additional step where $Na_3H(SO_4)_2$ is split into Na_2SO_4 and H_2SO_4, and the H_2SO_4 is returned to the ClO_2 generation process.

In the softwood mill the R8 process is selected. The $Na_3H(SO_4)_2$ by-product, is used to partially replace sulfuric acid used for soap splitting.

Since there is no soap splitting and an excess of sulfur in the birch mill the R10 process is selected to minimize the amount of excess sulfur (which is purged as recovery boiler precipitator ash).

3.11 OXYGEN SUPPLY

The oxygen demand of the oxygen delignification stage, EOP stage and other consumers is covered by oxygen generated on site in a Vacuum Pressurized Swing Adsorption (VPSA) plant.

At the capacity level required it is a simple and cost-efficient choice it can produce oxygen at up to 94% purity but does not provide a liquid oxygen back-up, so availability needs to be considered in the set-up, either by redundancy of key components or liquid oxygen import facilities. The plant may be owned by the mill or by an over-the-fence supplier.

The VPSA process is simple. Incoming ambient air is filtered, compressed, and conveyed to one or multiple zeolite beds. In the zeolite bed the nitrogen of the air is adsorbed while the oxygen passes through to a product oxygen receiver. When the zeolite bed is saturated with nitrogen it is closed off from the product receiver and the pressure reduced to desorb the nitrogen. The desorption and evacuation of the nitrogen is aided by a vacuum pump.

A booster compressor after the oxygen receiver increases the oxygen pressure to meet downstream process demands.

The VPSA ha a power consumption of 300 kWh/ton O_2(100%)

3.12 SULFURIC ACID PLANT

The chlorine dioxide and tall oil plants consume sulfuric acid, the sulfur content of which is returned to the recovery cycle. The result is a need to purge sulfur as sodium sulfate in recovery boiler ash from the recovery cycle. To reduce this purge and the associated sodium makeup demand the sulfur content of the concentrated odorous gases can be used to produce sulfuric acid. The content of sulfur in the CNCG is normally around 3-5 kg S/ADt at the sulfidity level and evaporation plant design here assumed and can with the help of black liquor heat treatment (LHT) be increased to up to 8 kg S/ADt. Here it is assumed that no LHT is included and that the sulfuric acid production from CNCG will be about 18 tons/d with imported sulfur used as support fuel and to cover the full sulfuric acid demand of the mill.

Two different sulfuric acid plants process configurations suitable for small and medium-sized plants have been installed in the kraft pulp industry, the single tower process and the Wet gas Sulfuric Acid (WSA) process. The single tower process will yield sulfuric acid with a concentration of 60% which is sufficient for internal use in the pulp mill. The WSA process yields 95-98% acid which matches commercial sulfuric acid specifications and can more easily be transported. The processes have very similar characteristics in terms of utilities consumptions, steam generation and environmental parameters.

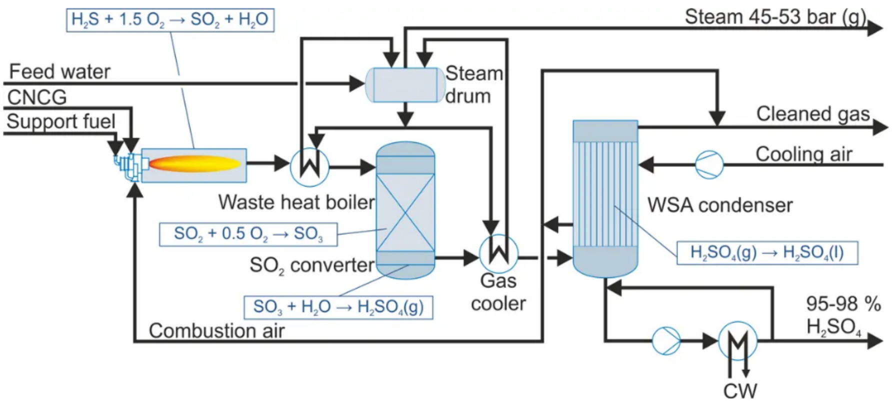

Figure 4. Wet gas Sulfuric Acid (WSA) process (courtesy of Andritz).

The combustion of the CNCG and support fuel produces some steam, in our case saturated MP steam.

The flue gas from the process is scrubbed with alkali and released to atmosphere.

3.13 EVAPORATION

The evaporation plant is a conventional 7-effect system utilizing LP and MP steam (Figure 5). It is designed to produce 83 % dry solids liquor (including recovery boiler ash).

All evaporator bodies are of the falling-film type, and the seven effects are designed to operate in counter-current fashion, i.e. with live steam being fed to the first effect through the train via the seventh effect to the surface condenser.

The heat in the hot extraction weak liquor from the digester area is recovered in the evaporation plant by multiple flash stages down to a liquor temperature suitable for storage at atmospheric pressure. Weak liquor from the atmospheric storage is flashed in multiple stages and then processed counter-currently to the vapour from the seventh to the first effect. An alternative design to the strict counter-current operation is to feed the weak liquor to the fourth effect in a co-current sequence through the seventh effect before feeding the liquor to the third effect.

Storage tanks are installed for weak, intermediate and heavy black liquors well as for soap, spills and condensates. The firing liquor storage tank is pressurized due to the high dry solids content with high viscosity.

Ash mixing is done prior feeding the first effect. Firing liquor at 83 % DS is produced in the final body of the first effect liquor sequence. The first effect is divided into three bodies connected in series on the liquor side. Washing of the first effect is done one body at a time using weak black liquor. To avoid upsets in firing liquor concentration when washing, and to facilitate ash mixing, an atmospheric heavy black liquor storage tank is placed on an intermediate heavy liquor from the second body in the first effect liquor sequence. The liquor from this same tank is also utilized for ash pick-up and the liquor is then returned to the first body in the liquor sequence of the first effect. Hence, the dry solids concentration is deliberately increased to ensure operation above the critical dry solids, to force precipitation by sodium salts in the bulk liquor instead of on the heating surface. The ash particles in the bulk liquor acts as seeds for the primary nucleation of the sodium salts.

The final body operating with the strongest liquor in the first effect is heated by intermediate pressure steam from a steam ejector driven by MP steam to compress LP steam. The other bodies in the first effect are heated by LP steam only. The vapor from the final body with the strongest liquor in the first effect has a pressure sufficient for utilization as motive steam in a separate dedicated portion of the heating surface in the first body of the liquor sequence of the first effect; hence this vapor operates in eight effects steam economy.

Sludge from the biological treatment is mixed into the black liquor in an intermediate storage tank.

3.13.1 Handling of condensates

The evaporator bodies are designed for condensate segregation with one larger amount of clean condensate and one smaller of contaminated condensate. A stripping system for foul condensates is integrated heat-efficiently in the evaporation plant with cleaning vapor from the first effect and heat recovery in the second effect. A methanol rectification column with a turpentine decanter and foul methanol liquid storage is also integrated. The methanol is incinerated in the recovery boiler.

Evaporation condensates are divided depending on contamination degree and distributed to different consumers within the mill. Approximately 4.5 m^3/ADt of the cleanest condensate (approximately 200 mg/l COD; 80°C) is used as wash liquor in the bleach plant. Approximately 3.5 m^3/ADt intermediate condensate (approximately 1000 mg/l COD, 65°C) is used in the causticizing plant. The remaining condensate is also clean condensate and is discharged as effluent.

The surface condenser is designed for a warm water temperature of 50°C and to provide condensate segregation in the same principle as the evaporator bodies.

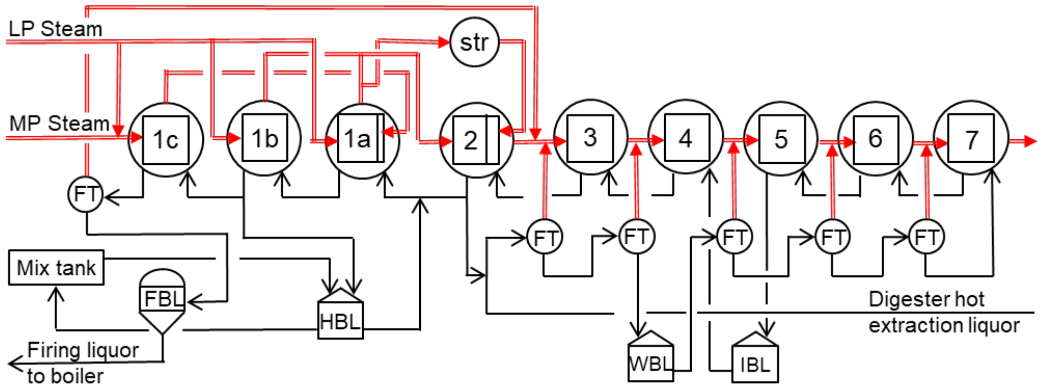

Figure 5. Evaporation plant including condensate stripper.

3.13.2 Handling of non-condensable gases

Non-condensable gases (NCGs) are collected throughout the mill. Both strong gases and weak gases can be burned in the recovery boiler. In mills which have a large excess of sulfur, an alternative is to incinerate the gases in a dedicated boiler and recover the sulfur in the flue gas as sulfuric acid in a separate plant. This solution is included in the softwood reference mill.

3.13.3 Tall oil recovery

Soap that separates in the weak and intermediate black liquor tanks is decanted to a soap decanter and then led to a separate storage tank. The soap is then pumped to the tall oil plant, where it is upgraded to crude tall oil. Hydrodynamic separators and centrifuges are the two most common technologies used today, giving high yields of tall oil from soap. The amount of soap depends on the wood used for pulping. With 50% pine and 50% spruce, the tall oil production is assumed to be 35 kg/ADt for softwood. There is usually no soap separated from birch liquor.

The most common type of tall oil plant uses sulfuric acid for soap splitting, and sulfur is thus added to the recovery cycle. Mills that use an R8 process for chlorine dioxide generation can use the sodium sesquisulfate ($Na_3H(SO_4)_2$) by-product to partly replace H_2SO_4 that would otherwise have been used for soap splitting.

Some mills use carbon dioxide to pretreat the soap. The product after this pretreatment is a mixture of soap and tall oil (soap oil), and a water phase containing sodium bicarbonate. The water phase is separated from the soap oil, and then the soap oil is treated with sulfuric acid as in a traditional tall oil plant. Pretreatment with carbon dioxide reduces the sulfuric acid requirement by about 40%.

3.14 RECOVERY BOILER

The optimum recovery boiler steam pressure and temperature is not the same in different regions. In Sweden many existing recovery boilers were designed when electricity prices were low. These boilers were in general designed for 60 bar steam pressure and corresponding temperatures. At higher steam temperatures more expensive metallurgy is required for the superheater, which means a sharp increase in investment and maintenance costs. Higher steam pressure and temperature cannot be economically justified with low electricity prices.

In contrast, Finland, for example, has had higher electricity prices, and the majority of recovery boilers operate at 80-90 bar. Globally, newer boilers are often designed for greater than 100 bar pressure to maximize power generation. With increasing electricity prices several new recovery boilers in Sweden have been designed for higher steam pressure and temperature.

In this study the recovery boiler is designed to produce high pressure steam at 110 bar(g) and 515°C. The selected steam data is currently at a limit for what is possible with existing materials and process chemistry in furnace. Because of these limitations it is unlikely that design pressure and temperature will increase substantially in the near future.

Some of the key factors in the recovery boiler design which are related to maximizing power generation include:

- Feedwater preheating with both MP and MP2-steam, which increases steam generation and consequently the power generation. MP-steam is used for preheating before the economizer and MP2-steam as interheating after the first economizer step. The pressure (and temperature) in the feedwater tank is maximized and restricted by the pressure in the LP-steam system. One drawback of feedwater preheating is increased flue gas temperature after the economizer which increases the flue gas loss and increases the cost of the precipitator. In order to maximize power generation, MP-steam is prioritized for feedwater preheating.

- Flue gas cooling after the precipitator – the heat uptake in the cooler will commonly replace LP steam for combustion air preheating. Any surplus heat from the flue gas cooling circuit, exceeding heat consumption for air preheating, is utilized for demineralized water preheating. The LP steam can instead be sent to a condensing turbine to produce power. This also reduces the negative impact of increased flue gas temperature due to feedwater preheating. Flue gas temperature after the cooler is set to 125°C.

- Preheating of all combustion air to about 205°C to increase power generation. In order to maximize power generation, MP-steam is prioritized for air preheating prior MP2-steam.

- Sootblowing steam at 25 bar(g) is extracted from the turbine instead of using high pressure steam from the recovery boiler. Lower pressure for sootblowing has at present not been commercialized at large scale. Sootblowing steam consumption is minimized through operational adjustments, for example one way sootblowing.

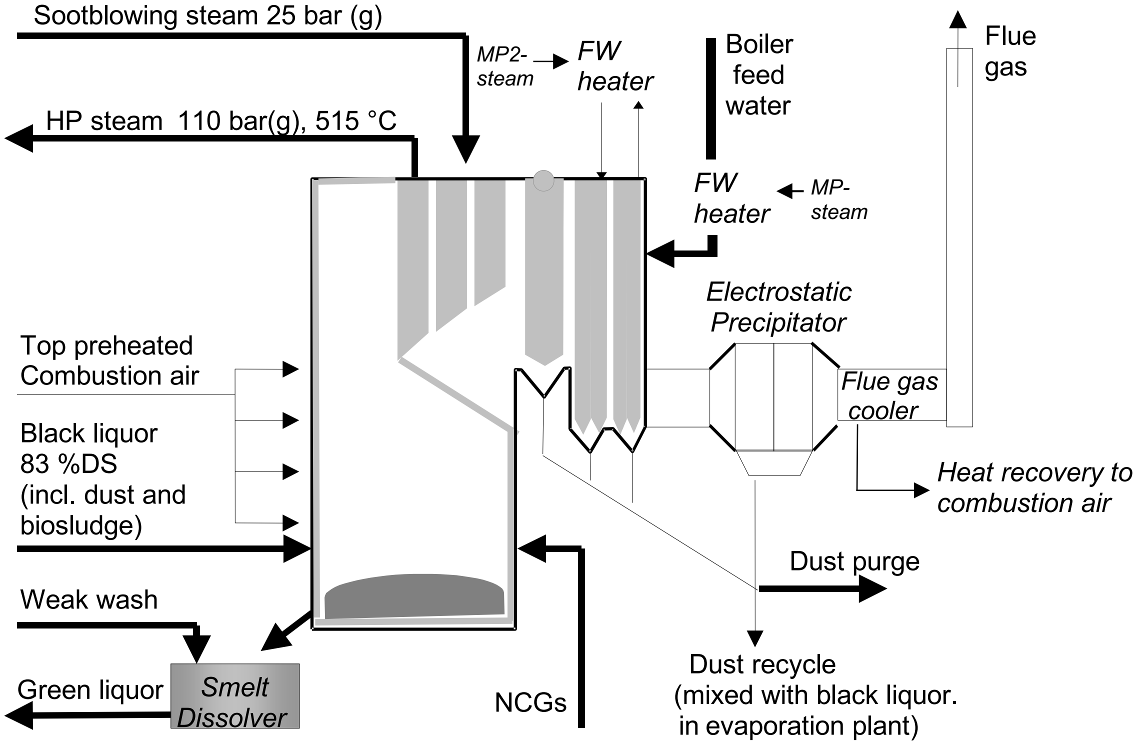

Figure 6. Recovery boiler and smelt dissolver.

The high liquor concentration contributes to a high bed temperature, which leads to low sulfur emissions from the bed. Modern boilers with high energy features often have black liquor concentrations of 82% DS (virgin). Going beyond this point increases steam production but may also lead to more difficult operation.

Combustion air is distributed on multiple levels to facilitate complete combustion and minimize NO_x formation. Dust that is not captured in the economizer section is removed in the electrostatic precipitator (ESP). Most of the dust is recycled and mixed with the black liquor in the evaporation plant, as described in section 3.13. A fraction of the dust is purged, mainly to control sulfur and sodium, with the additional benefit of reducing potassium and chloride concentrations in the liquor cycle.

With increased recovery boiler temperature and pressure, the tolerance for potassium and chloride in the black liquor is reduced. At the design pressure and temperatures for this boiler the maximum chloride concentration in the liquor is about 0.3 wt% and about 1.5% for potassium. Exceeding these concentrations increases the risk for recovery boiler corrosion and plugging problems.

Softwood and birch have relatively low levels of chloride and potassium, but the recycling of EOP filtrate increases chloride levels in the black liquor. A large purge of recovery boiler ash would be required to manage the chloride and potassium, and the cost for makeup chemicals would be high. A chloride removal system to treat recovery boiler ash has thus been included for both the softwood and birch reference mills. Either an ash leaching process, or an evaporative crystallizer process can be used for chloride removal.

3.15 CAUSTICIZING

The green liquor is filtered in parallel green liquor filter units. Alternatively, the green liquor can be clarified in a high-rate clarifier. The dregs are washed and dewatered in two decanter centrifuges in series before being discharged. Condensate from the evaporation plant is used for dregs washing. Dregs and grits are combined and sent to landfill.

Green liquor from the storage tank is cooled in a flash-type green liquor cooler before the lime slaker-classifier. Slaking and causticizing is performed in a single line with causticizing vessels in series.

The causticized liquor is filtered in a pressure disc filter. The main advantage of disc filters over other types of white liquor filters is the low liquor content of the discharged lime mud which eliminates the need for a separate lime mud washing stage.

Lime mud from the lime mud vessel is pumped to the agitated lime mud storage tanks. The lime mud is washed and dewatered on a lime mud disc filter. Condensate from the evaporation plant is used for lime mud dilution and hot water for the lime mud filter wash showers.

Spills are reclaimed from two spill sumps and pumped to the weak wash storage tank.

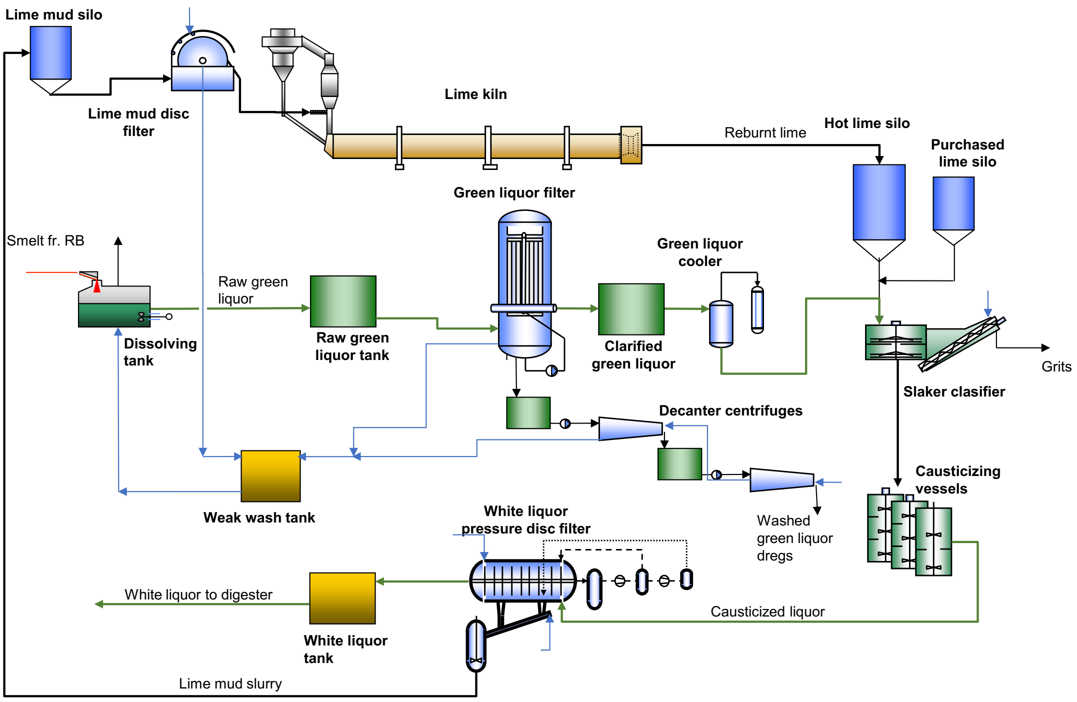

Figure 7. White liquor preparation.

3.16 LIME KILN

The single lime kiln is equipped with an external lime mud dryer and a modern product cooler. The product cooler could be of a rotary type mounted on the kiln or a moving grate cooler which provides a somewhat higher air temperature to the kiln and a steeper temperature profile in the kiln.

Dust is removed from the flue gases by means of an electrostatic precipitator. The ID fan is installed downstream the precipitator.

A fraction of the lime mud is purged and used for external purposes, primarily to control phosphate levels. Limestone or lime is used for make-up.

The kiln is fired with gas from a biomass gasifier fed with dried bark and wood residues. The bark dryer uses mainly heat recovered from the lime kiln flue gases over a pressurized hot water loop. The lime kiln heat recovery unit is placed after the electrostatic precipitator and is of coiled tube type for high heat transfer capacity.

The gasifier design is a circulating fluidized bed (CFB) with limestone as the bed material (Figure 8). The temperature in the gasifier is 750-850°C.

The system consists of the gasifier, a cyclone to separate the circulating bed material from the gas, and a return pipe for returning the circulating material to the bottom part of the gasifier. The gasification air, blown with the high-pressure air fan, is fed to the bottom of the reactor via an air distribution grid. When the gasification air enters the gasifier below the solid bed, the gas velocity is high enough to fluidize the particles in the bed.

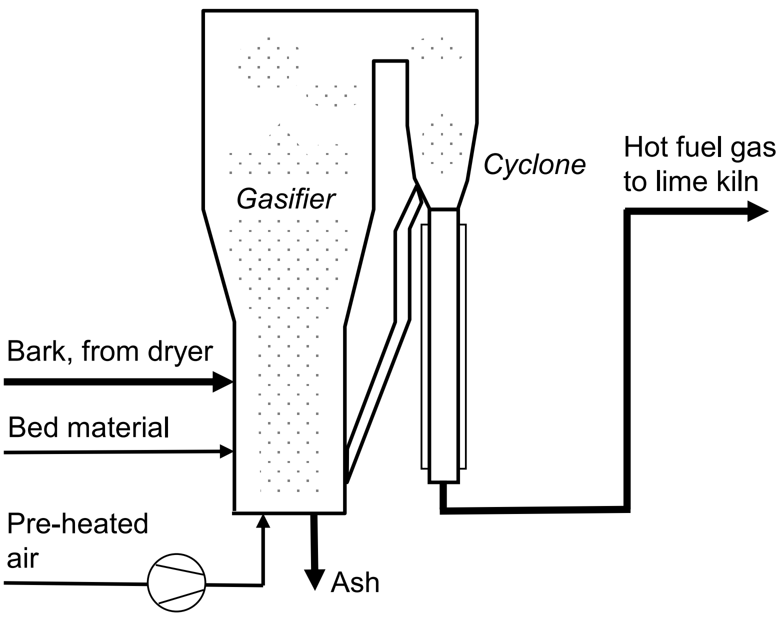

Figure 8. Bark gasifier for production of fuel gas to lime kiln.

The fuel gas is transferred at a temperature of approximately 700°C to the lime kiln burner. Slightly less than half of the falling bark is fed to the bark gasifier, corresponding to ca 6.5 GJ/t lime produced.

An alternative is to fire the kiln with wood powder, a solution used in several Swedish mills. Recent installations in large market pulp mills in Finland and globally have mainly been gasifiers [6], at least partly because a large amount of bark otherwise needs to be sold. In large installations the higher investment cost of a gasifier is thus more easily justified. Tall oil pitch is currently the most common biofuel used in lime kilns in Sweden, and to some extent in Finland, but is limited in availability.

3.17 POWER BOILER

The recovery boiler alone produces more than enough steam for the processes and power generation. However, since bark is readily available, even after feeding fuel for the lime kiln, a power boiler is included to produce additional HP steam. All excess steam is used in a condensing steam turbine to generate power for sale. Whether this is economically attractive depends on electricity and biomass prices in the location of the mill.

The power boiler has the same steam parameters as the recovery boiler and is connected to the common feed water tank.

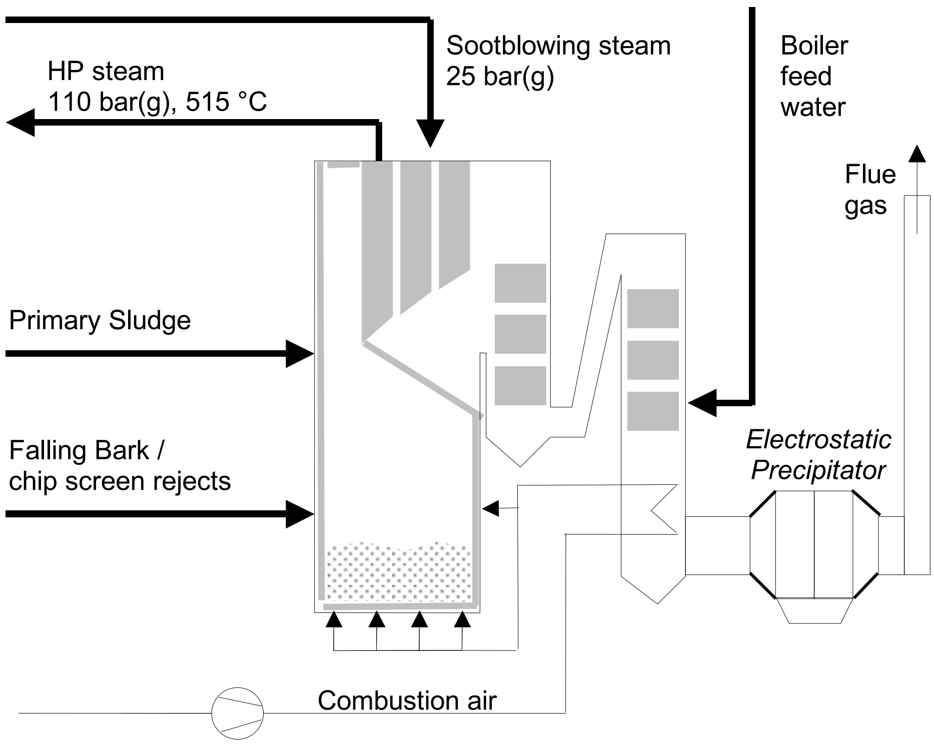

Figure 9. Power boiler burning bark and sludge.

Primary sludge from the effluent treatment plant is also incinerated in the power boiler. The boiler can, in certain circumstances, be designed to allow incineration of all sludge qualities from effluent treatment.

The power boiler is designed to provide steam for mill start-up and shutdowns, and there is no need for an additional boiler dedicated for start-ups and shutdowns.

The power boiler is designed with a bubbling fluidized bed (BFB).

3.18 STEAM TURBINES AND STEAM DISTRIBUTION

Steam is reduced through a backpressure steam turbine to 3.0 bar(g). This pressure has been selected to facilitate maximum electric power production without requiring unnecessary large evaporator bodies or heat surfaces in the pulp dryer. Intermediate pressure steam of 25 bar(g) is extracted for soot blowing and 9 bar(g) steam is extracted to the MP-steam system.

MP steam and LP steam are desuperheated with boiler feedwater before distribution. However, with increasing turbogenerator efficiencies and selected steam parameters, the foreseen de-superheating requirement are low or zero. Provisions in steam distribution system for long term operation in or close to wet steam region is considered.

HP steam not required in the process is utilized in a condensing steam turbine for further electric power generation.

Table 3-5. Steam data.

	°C	bar(g)
HP steam	515	110.0
MP2 steam, extracted for sootblowing and preheating	275	25.0
MP steam, desuperheated	195	9.0
LP steam, desuperheated	144	3.0

3.19 COOLING AND RECOVERY OF LOW-TEMPERATURE HEAT

In addition to normal heat losses of different kinds, approximately one third of all the energy that is introduced with the fuel to the system will have to be cooled away by a cooling system. The secondary energy system comprises the recovery of heat that is generated from steam and electricity and that is finally withdrawn from the system by cooling. In principle, the system can be divided into two parts: one where heat is recovered for the production of warm and hot water, another part where excess heat is cooled by the means of a cooling tower. The design of the reference mill is conventional, except for the very low fresh water consumption.

Low-temperature heat is recovered from a number of sources in the kraft mill, e.g., the surface condenser of the evaporation plant, the smelt dissolver vapor condenser, and the turpentine condenser. The heat is used for hot water production and for boiler feed-water heating. Condensate from the evaporation plant is used in the pulp washing and in the lime mud wash.

The cooling water system is integrated with the process water system. Cooling is carried out in cooling towers.

It is common for pulp and paper mills in the Nordic countries to sell excess heat to district heating systems, especially if the mill is located close to a town or city. Such solutions are efficient both because they reduce the amount of primary energy needed to supply heat to the district heating system and the amount of cooling that is needed in the mill. Integration with district heating or other users of excess heat has not been included in the reference mill, however, since the optimal solution will vary greatly between locations.

3.20 EFFLUENT TREATMENT

Effluent treatment consists of pretreatment (cooling equipment and neutralization), primary clarification and biological (secondary) treatment. To meet the discharge limits for all parameters some polishing stage might also be needed. A block diagram is shown in Figure 10.

There is a primary clarifier to remove fiber sludge from high solids effluent. The estimated suspended solids content of the high solids process streams from the pulp mills is about 300 mg/l. After the clarifier the suspended solids content is about 50 mg/l. The primary sludge is dewatered in a centrifuge and incinerated in the power boiler (alternatively the primary sludge could be sold to a fluting mill or similar, depending on the cost efficiency). After the primary clarifier the effluent is mixed with low solids effluent, screened, cooled to about 35°C and the pH is adjusted to about 7.

Table 3-6. Outlet from primary clarifier and pre-treatment.

		Softwood	Birch
Total flow	m^3/ADt	25	25
	m^3/d	100 000	100 000
Flow from primary clarifier	m^3/d	50 000	50 000
COD	kg/ADt	29	27.5
	kg/d	116 000	110 000
SS, total flow	kg/ADt	4.5	4.5
	mg/l	45	45
	kg/d	4 500	4 500
Temperature	°C	~35	~35
pH		~7	~7
Primary sludge	t DS/d	12.5	12.5

For biological treatment there is an MBBR (Moving Bed Biofilm Reactor) reactor with suspended carriers followed by an activated sludge system, often called BAS (Biofilm + Activated Sludge). In the activated sludge system, there is an aeration basin and a secondary clarifier. Return sludge is pumped from the clarifier to the inlet of the aeration basin to keep a high level of activated sludge (micro-organisms) in the basin. The system is designed for low biosludge production and low nutrient discharges. The COD reduction is estimated to be about 65-70% for the softwood production and about 70-75% for the hardwood production.

The suspended solids concentration out from the secondary clarifier (BAS system) is about 50 mg/l for the market pulp cases.

The biological sludge is dewatered to about 10% in a centrifuge and mixed with intermediate black liquor in the evaporation plant, before incineration in the recovery boiler.

For some receiving waters higher demands than the lower level of the BAT-AEL ranges can be demanded for some parameters. This can be hard to fulfil without a final filter or other polishing stage.

The discharge values after biological treatment to the recipient are shown in Table 3-7.

The biological sludge production factor is estimated at 0.15 kg/kg COD reduced.

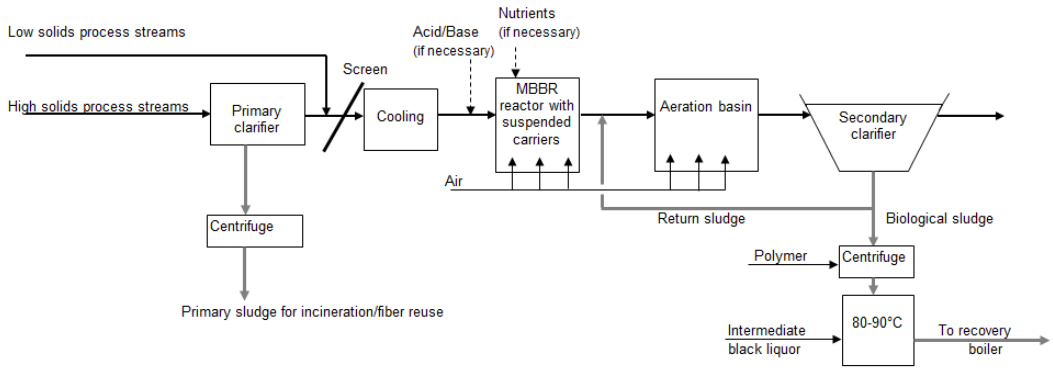

Figure 10. Effluent treatment plant

Table 3-7. Outlet data from biological effluent treatment at normal production.

		Softwood	Birch
Flow	m³/ADt	25	25
COD reduction BAS	%	65-70	70-75
COD out BAS	kg/ADt	~9-11	~8-10
	t/d	35-40	30-35
TSS out BAS	kg/ADt	1.25	1.25
	mg/l	50	50
	t/d	5	5
Biological sludge	t/d	12	11-12

There are European BAT-AEL limits for discharges from pulp and paper mills. Those limits are expressed as intervals of discharge per ton of product for different types of production. The values for bleached Kraft pulp are given in Table 3-8. For modern mills the lower part of the interval must normally be reached.

To reach very low nutrient discharges when high COD reduction rates are demanded is a challenge.

Table 3-8. BAT-AEL for effluent to recipient from bleached Kraft pulp mills and paper mills [7].

		Bleached Kraft Pulp
Flow	m³/ADt	25-50[1)]
COD	kg/ADt	7-20
TSS total suspended solids	kg/ADt	0.3-1.5
Total nitrogen	kg/ADt	0.05-0.25
Total phosphorus	kg/ADt	0.01-0.03
AOX adsorbable organic bound halogens	kg/ADt	0-0.2

1) The flow values are not BAT-AEL values

3.21 SPILL HANDLING SYSTEM

Accidental spills caused by abnormal operation or equipment failures can be a significant contribution to the effluent emissions from the mill, and therefore it is important to minimize spills.

The mills are designed with comprehensive sewer systems to collect accidental spills as close to the source as possible and directly recycle them to the proper process stage. The evaporation plant is designed with additional capacity to take care of black liquor spills in that area, as well as possible liquor contaminated condensates.

The spill system includes:

- Adequate instrumentation to minimize the risk for overflow of tanks and equipment, and to detect accidental spills.
- Provisions to take care of process liquors when it is necessary to empty tanks or equipment for maintenance
- Retention dams around tanks and equipment.
- Floor channels connected to pump sumps from which liquids can be pumped back to the process.
- Emergency effluent treatment pond for major spills or upset conditions in the effluent treatment plant.
- Well-educated and trained personnel who understand the importance of spill handling.

3.22 WATER SUPPLY AND TREATMENT

Water is commonly used for two main purposes in the mill: process water and cooling. Other areas of use are fire water and maintenance.

The raw water quality is normally high in Nordic rivers, with low content of suspended solids and chemical pollutants. There are however seasonal and interannual variations to be considered, as well as change in raw water quality as a consequence of climate change.

The mill water system has only one quality, chemically treated water, with the following treatment sequence (Figure 11).

- Water intake with coarse screening
- Reduction of fine suspended solids using mesh filtration
- Chemical precipitation followed by dissolved air flotation (DAF)
- Sand filtration
- Clear water well, including storage capacity for fire fighting

Table 3-9. Data, raw water treatment.

Flow	m^3/d	90 000 – 110 000
Raw water sludge	kg/d	~4 400

The raw water intake should be arranged and designed to minimize the amount of sand and other debris entering the mill.

As precipitation chemical some kind of Al-salt is used and pH adjusted to an optimum using NaOH. To enhance flocculation properties a polymer is added. Raw water sludge is discharged to the receiving water together with treated effluent.

Part of the chemically treated water is further treated to feedwater to be used in the recovery boiler and the power boiler. The demineralized water treatment plant comprises ultra filtration, reverse osmosis and ion exchange. Dosage of sodium hypochlorite, sodium bisulphite, sodium hydroxide antiscalant and biocide is foreseen. The plant is designed for a flow of 10 000 m^3/d.

The cooling water system is semi-open, which means that part of the process water comes from the cooling water system. The cooling is performed in a cooling tower. There are filters in the cooling water system to avoid impurities in the mill process water.

The amount of process water coming from the cooling system is controlled so that the cold water temperature is maintained at about 18°C.

There is a separate cooling water loop for the turbine and the turbine condenser. The water from the turbine oil cooler is dumped. Other coolers in the mill are connected to the general mill process water system. Water from such coolers that could contaminate the water should also be dumped.

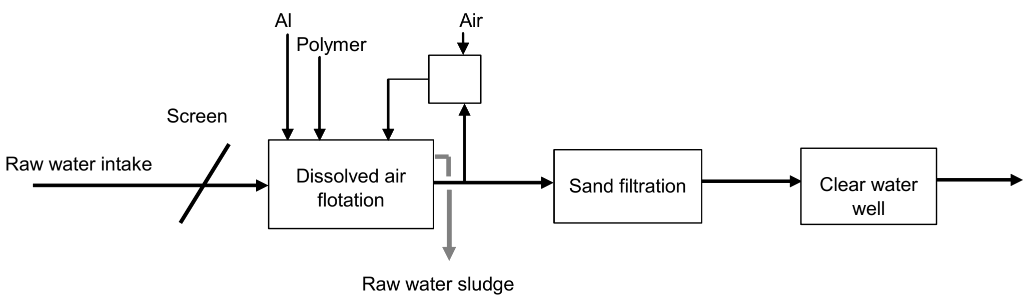

Figure 11. Water treatment.

4 Reference mills - energy balances

The reference mills are designed to be energy efficient. The mills would be self-sufficient in both power and steam with only the recovery boiler and back pressure turbine. The mills have a power boiler to make use of surplus bark/wood waste and for sludge recovery.

The lime kiln is fired with gasified bark, and the remaining bark from the woodyard and chip screening is co-fired with sludges from effluent treatment in the power boiler.

There is an excess of steam from the recovery and power boilers which is utilized in a condensing turbine to produce renewable power for export.

Key factors which make the reference mill energy efficient include:

- High HP steam data 110 bar(g), 515°C
- Feed water preheating to 175°C with MP-steam and interheating with MP2-steam to increase HP steam generation
- Recovery boiler flue gas cooler to replace LP steam consumed in air preheating
- Top preheating of all recovery boiler combustion air to 205°C
- Recovery boiler sootblowing steam is extracted at 25 bar(g) from the turbine instead of using HP steam
- Latest technology for pulp digesting which has a lower cooking temperature than other systems
- 7 effect evaporation plant with hot feed of weak black liquor; "hot liquor flash"
- Steam consumption in the bleach plant is reduced; more chlorine dioxide and less hydrogen peroxide allow a lower bleaching temperature
- Shoe press system in pulp dryer
- Low pressure steam used in the pulp dryer
- Pressurized condensate system
- High temperature of hot water, >85°C, and maximum use of hot water instead of steam in the bleach plant and pulp machine
- Bark press for bark to the power boiler
- MP-steam heat recovery from H_2SO_4 plant (softwood)

Depending on electricity prices there are some mills which have had more focus on design with lower total power consumption to reduce the amount of purchased power required (or maximize sold power).

An overview of the energy system and balances for the reference mills are shown in Figure 12 and Figure 13. More detailed balances can be found in Appendix C-G.

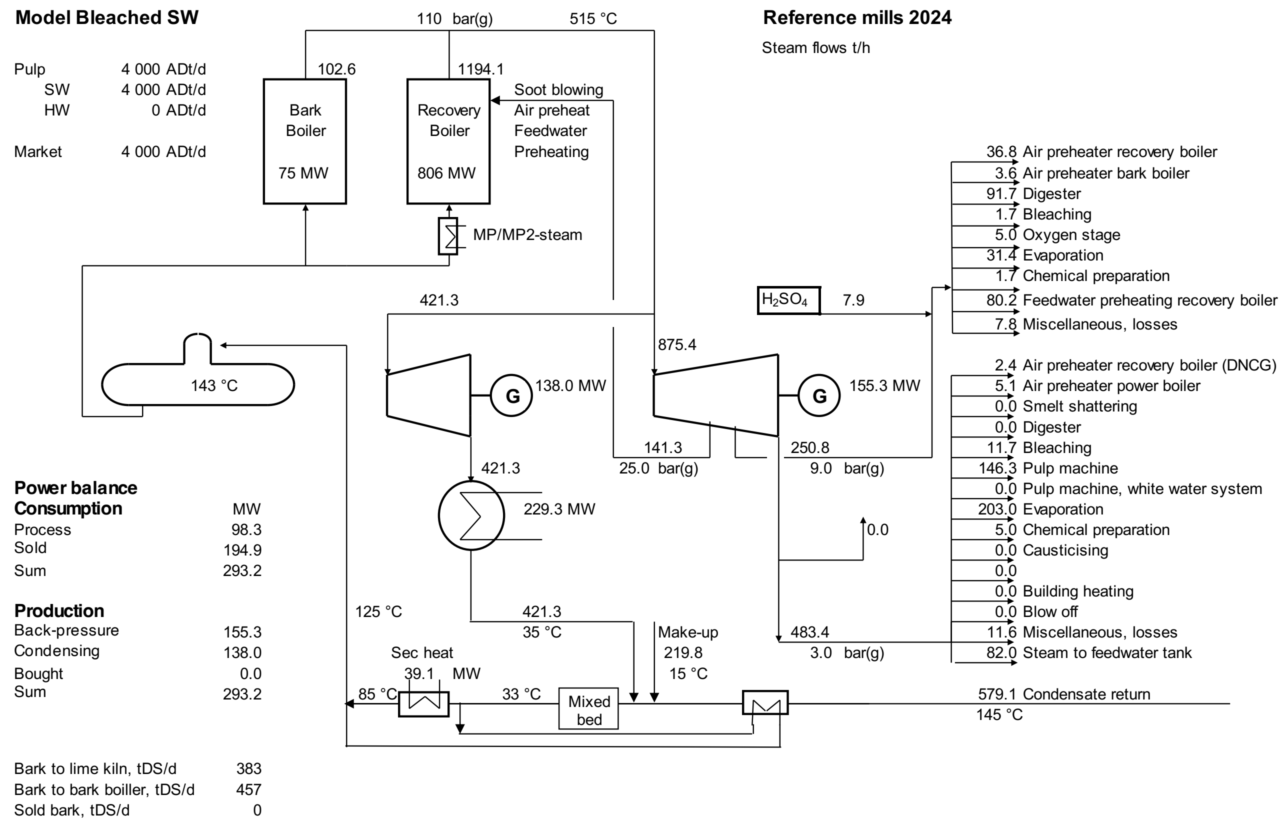

Figure 12. Overall energy balance for the softwood bleached market pulp reference mill.

The process steam consumption in the softwood reference mill is about 8.4 GJ/ADt. Heat generated from black liquor and falling bark amounts to about 20 GJ/ADt (880 MW) and there is thus a large excess of steam that is used for electricity generation.

Approximately two thirds of the generated steam pass the back-pressure turbine to produce 155 MW of electric power. The remaining steam is fed to the condensing turbine, which generates a similar amount of electric power, ca 138 MW. Power consumption in the process is ca 98 MW. There is thus a potential to sell as much as 195 MW, corresponding to more than 1.15 MWh/ADt.

Process steam consumption in the birch reference mill is slightly lower, ca 8.1 GJ/ADt, mainly because the pulp yield is higher than for softwood, resulting in less black liquor and a smaller evaporation demand.

Because of the smaller amount of black liquor to recovery boiler in the birch mill, the amount of steam generated is about 15% smaller. The total steam generation in the mill is compensated by the fact that there is more bark available in the birch mill. This is an indirect effect of the use of saw mill chips as part of the feedstock in the softwood mill, giving less falling bark in that case. Power consumption in the birch mill is ca 93 MW. There is a potential to sell 182 MW, corresponding to ca 1.09 MWh/ADt.

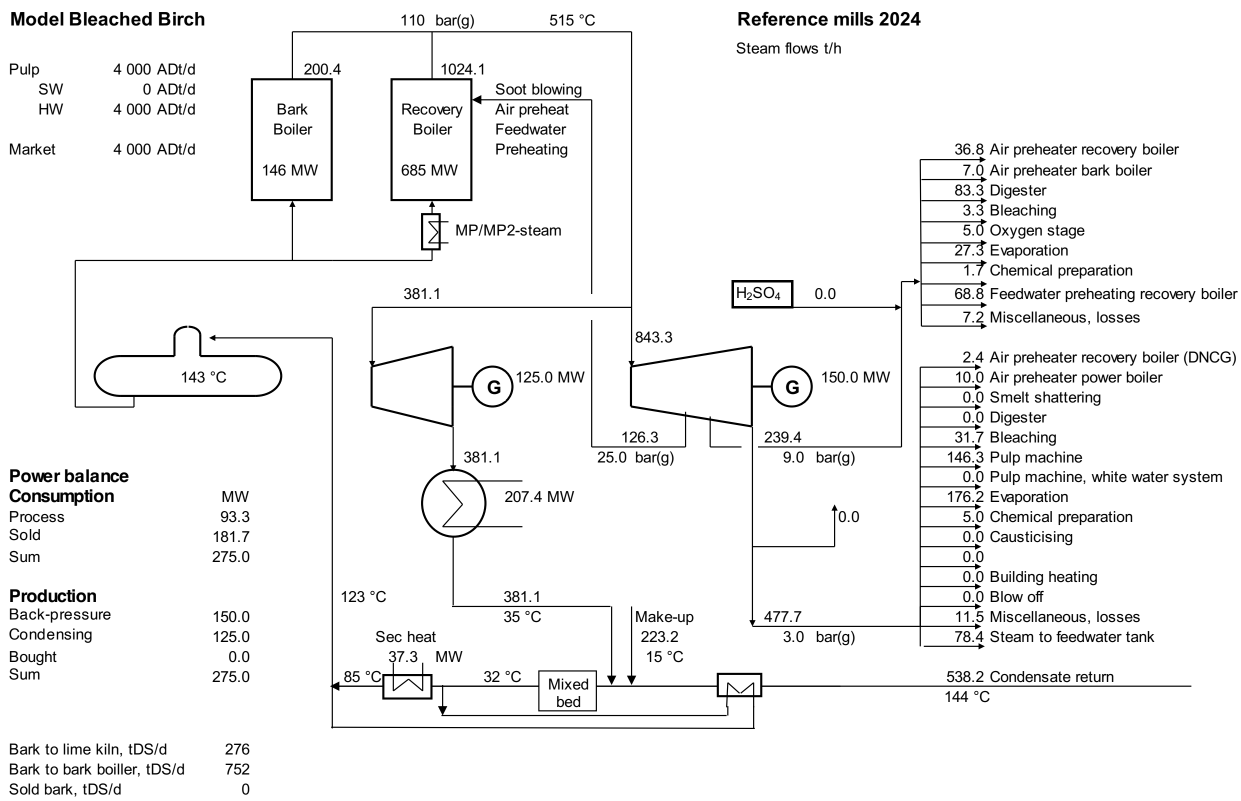

Figure 13. Overall energy balance for the hardwood bleached market pulp reference mill.

Table 4-1 compares the overall steam and power balances for the 2024 reference mills and the 2010 reference mills. There are relatively small differences in process steam consumption of about 5%, but the differences are larger in the power consumption which has been reduced by ca 15% on average, e.g. due to efficiency of scale and increased use of variable frequency drives.

The decreased power consumption together with the increases in power generation, mainly due to the more advanced steam data and decreased steam consumption, leads to a large increase in the potential to sell excess power, ca 0.25 MWh/ADt for both the softwood and birch cases. The resulting power export for the 2024 reference softwood mill is thus ca 30% higher than for the 2010 reference mill.

Table 4-1. Summary of steam and power balances in the 2024 and 2010 reference mills.

	2024		2010	
	Softwood	Birch	Softwood	Birch
STEAM BALANCE (GJ/ADt)				
Production				
Recovery boiler	17.41	14.80	17.82	14.72
Power boiler	1.61	3.14	1.53	2.89
H2SO4 heat recovery	0.11	0.00	-	-
Secondary heat	0.85	0.81	0.69	0.63
Total steam generation	19.97	18.75	20.04	18.24
Consumption				
Process steam	8.45	8.12	8.90	8.47
Back pressure turbine	3.48	3.36	3.12	2.92
Condensing turbine	8.04	7.28	8.02	6.86
Total steam consumption	19.97	18.75	20.04	18.24
POWER BALANCE (kWh/ADt)				
Generation				
Back pressure power	932	900	836	782
Condensing power	828	750	783	671
Total power generation	1 759	1 650	1 619	1 452
Consumption				
Mill consumption	590	560	724	640
Sold power	1 169	1 090	895	812
Total power consumption	1 759	1 650	1 619	1 452

5 References

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Appendix A. Sulfur balance for the reference mills (kg/ADt).

	Softwood	Birch
Inorganics in the raw material	0,16	0,15
Make up as Na2SO4	1,32	-
Make up as MgSO4	0,63	0,27
Waste product from ClO2-plant	4,62	2,97
Waste product from tall oil plant	0,96	-
External liquor supply	0,18	0,16
TOTAL IN	**7,87**	**3,55**
Wash loss	0,70	0,69
Unspecified losses black liquor	0,16	0,16
Unspecified losses white liquor and ox white liquor to effluent	1,38	0,16
Digester and evap. condensate	0,00	0,00
Dregs and grits	0,20	0,20
Sewered from CRP	0,67	0,77
Purged precipitator dust	-	1,22
Emitted from weak gas system	-	-
Diffuse Emissions	0,10	0,10
H2S from Recovery Boiler	0,01	0,01
Emission (SO2) from recovery boiler	0,03	0,16
Emission (dust) from recovery boiler	0,06	0,05
Dust from smelt dissolver	0,01	0,01
Emission from lime kiln, SO2	0,00	0,00
Emission from lime kiln, H2S	0,01	0,01
Emission from lime kiln, dust	0,00	0,00
Dust from lime kiln scrubber/filter	0,00	0,00
Emission from NCG incinerator, SO2	4,53	0,00
TOTAL OUT	**7,87**	**3,55**

Appendix B. Sodium balance for the reference mills (kg/ADt).

	Softwood	Birch
Inorganics in the raw material	0,48	0,49
Make up as Na2SO4	1,90	0,00
Sulfur-free alkali make up	0,01	0,50
Waste product from ClO2-plant	4,98	4,27
External liquor supply	3,87	3,51
TOTAL IN	**11,23**	**8,76**
Wash loss	2,65	2,66
Unspecified losses black liquor	0,65	0,65
Unspecified losses white liquor and ox white liquor to effluent	5,60	0,65
Digester and evap. condensate	0,01	0,01
Dregs and grits	0,65	0,65
Sewered from CRP	1,42	1,63
Purged precipitator dust	-	2,27
Emission from recovery boiler, particulate	0,09	0,08
Dust from smelt dissolver	0,03	0,03
Emission from lime kiln, particulate	0,01	0,01
Dumped dust from lime kiln	0,12	0,12
TOTAL OUT	**11,23**	**8,76**

Appendix C. Specific power consumption and generation in the 2024 reference mills, kWh/ADt.

	2024	
	Softwood	Birch
Power consumption		
Wood yard	25	30
Digester	30	30
Washing and O2 delignification	105	100
Bleaching	45	40
Final screening	-	-
Pulp machine	115	115
Evaporation	35	30
White liquor production[1]	30	25
Recovery boiler[2] and power boiler	115	105
Cooling towers	25	25
Raw water treatment and distribution	15	15
Effluent treatment	15	15
Chemicals preparation[3]	25	20
Miscellaneous, losses	10	10
Sum	590	560
Sold power	1 169	1 090
Total	1 759	1 650
Power generation		
Back-pressure power	932	900
Condensing power	828	750
Bought power	0	0
Sum	1 759	1 650

[1] Includes bark dryer and gasifier
[2] Includes ash treatment
[3] Includes sulfuric acid plant and air separation unit

Appendix D. Bark balance in the 2024 reference mills, tDS/ADt.

	2024	
	Softwood	Birch
Bark from woodyard	0.210	0.257
Bark to lime kiln	0.096	0.069
Bark to bark boiler	0.114	0.188

Appendix E. Specific steam consumption in the 2024 reference mills, GJ/ADt.

	2024	
	Softwood	Birch
Steam consumption		
Wood yard	0	0
Digester	1.51	1.38
O2 delignification	0.08	0.08
Bleaching	0.21	0.56
Pulp dryer	2.07	2.07
Evaporation	3.08	2.67
White liquor production	0.00	0.00
Recovery boiler, sootblowing and blowdown	1.08	0.92
Power boiler, sootblowing and blowdown	0.02	0.04
Chemicals preparation	0.10	0.10
Miscellaneous, losses	0.30	0.29
Total	8.45	8.12

Appendix F. Energy balance for the 2024 softwood reference mill.

ENERGY BALANCE — **Model Bleached SW**

ASSUMPTIONS			Enthalpy etc kJ/kg	Temp °C	Pressure bar(g)
Make-up water before preheating			63	15	
Make-up water, preheated by sec heat			357	85	
Turbine cond., preheated by sec heat			357	85	
Feedwater to boilers			609	143	
HP-steam			3400	515	110.0
MP2-steam, desuperheated			2944	275	25.0
MP-steam, desuperheated			2814	195	9.0
LP-steam, desuperheated			2738	144	3.0
Mech./el efficiency turbine	-		0.97		
Dry solids to recovery boiler	t/d		7061		
Net useful heat from liquor	MW		806		
Bark fuel from wood yard	DS t/d		840		
from that to lime kiln	DS t/d		-383		
sold bark	DS t/d		0		
sludge etc, as wood fuel	DS t/d		0		
bark to power boiler	DS t/d		-457		
Net useful heat from fuel in bark boiler	MW		75		
		ADt/d			
Produced pulp, MCR		4000			
of which softwood		4000			
of which hardwood		0			
Market pulp		4000			

:

STEAM CONSUMPTION	Steam Flow t/h	Temp °C	Condensate Flow t/h	Heat Effect MW
HP-steam				
Back-pressure turbine				160.9
MP2-steam	(141.3)			
MP-steam	(250.8)			
LP-steam	(483.4)			
Condensing turbine				372.2
condensing steam	421.3	35	421.3	
Direct reduction HP-MP	(0.0)			
Direct reduction HP-LP	(0.0)			
Soot blowing recovery boiler	0.0		0.0	0.0
Blow down recovery boiler	6.0		0.0	2.2
Soot blowing bark boiler	0.0		0.0	0.0
Blow down bark boiler	0.5		0.0	0.2
Total HP-steam	427.8		421.3	535.5
MP2-steam				
Soot blowing recovery boiler	59.7		0.0	47.8
Air preheater recovery boiler	29.3	160	29.3	(18.5)
Feedwater interheater, recovery boiler	57.5	200	57.5	(33.6)
Soot blowing power boiler	1.0		0.0	0.8
Total MP2-steam	147.6		86.8	48.6
MP-steam				
Air preheater recovery boiler	36.8	170	36.8	(21.4)
Air preheater bark boiler	3.6	170	3.6	(2.1)
Feedwater preheater, recovery boiler	80.2	180	80.2	(45.9)
Digesting	91.7	170	0.0	70.1
Bleaching	1.7	180	0.0	1.3
Oxygen stage	5.0	100	0.0	3.8
Evaporation	31.4	140	29.8	19.7
Chemical preparation	1.7	100	0.0	1.3
Miscellaneous, losses	7.8	100	2.3	5.7
Total MP-steam	259.8		152.7	101.8
LP-steam				
Air preheater recovery boiler	2.4	148	2.4	(1.4)
Air preheater bark boiler	5.1	148	5.1	(3.0)
Woodyard	0.0		0.0	0.0
Digesting	0.0		0.0	0.0
Bleaching	11.7		0.0	8.7
Pulp machine	146.3	100	131.7	95.7
Evaporation	203.0	140	192.8	122.7
Hot water production	0.0	130	0.0	0.0
Chemical preparation	5.0	100	4.0	3.3
Causticising	0.0	100	0.0	0.0
Heating etc	0.0	100	0.0	0.0
Blow off	0.0	100	0.0	0.0
Miscellaneous, losses	11.6	100	3.5	8.2
Steam to feedwater tank	82.0		82.0	
Total LP-steam	467.0		421.4	238.7

SUMMARY STEAM CONSUMPTION	Flow t/h	Temp °C	Flow t/h	Effect MW
HP-steam	427.8		421.3	535.5
MP2-steam	147.6		86.8	48.6
MP-steam	259.8	168	152.7	101.8
LP-steam	467.0	124	421.4	238.7
Make-up water			219.8	
TOTAL STEAM CONSUMPTION	1302.1		1302.1	924.5

STEAM PRODUCTION		Steam Flow t/h	Heat Effect MW
Recovery boiler	t/ADt		
HP-steam	7.16	1194.1	925.5
soot blowing		0.0	0.0
blow down		6.0	1.3
feedwater preheat MP			-45.9
feedwater preheat MP2, inter eco			-33.6
air preheating, LP-steam			-1.4
air preheating, MP-steam			-21.4
air preheating, MP2-steam			-18.5
Sum		1200.1	806.0
Extern överhettare			0.0
Bark boiler	t/ADt		
HP-steam	0.62	102.6	79.6
soot blowing		0.0	0.0
blow down		0.5	0.1
air preheating, LP-steam			-3.0
air preheating, MP-steam			-2.1
Sum		103.2	74.55
MP-steam from boilers (H2SO4)		7.9	4.9
desuperheating water MP2-steam		6.2	
desuperheating water MP-steam		1.1	
drainage water LP-steam		-16.4	
Secondary heat for preheating make-up water			39.1
TOTAL STEAM PRODUCTION		1302.1	924.5

POWER CONSUMPTION	kWh/ADt	MW
Wood yard	25	4.2
Digester	30	5.0
Washing and screening, O2 delignification	105	17.5
Bleaching	45	7.5
Pulp machine	115	19.2
Evaporation	35	5.8
Causticising, lime kiln incl.gasifier	30	5.0
Boiler house	115	19.2
Cooling tower etc	25	4.2
Raw water treatment and distribution	15	2.5
Effluent treatment	15	2.5
Chem preparation	25	4.2
Miscellaneous, losses	10	1.7
Sum	590	98.3
Sold power	1169	194.9
Total	1759	293.2
POWER PRODUCTION		
Back-presssure power	932	155.3
Condensing power	828	138.0
Bought power	0	0.0
Sum	1759	293.2

Appendix G. Energy balance for the 2024 birch reference mill.

ENERGY BALANCE **Model Bleached Birch**

ASSUMPTIONS		Enthalpy etc kJ/kg	Temp °C	Pressure bar(g)
Make-up water before preheating		63	15	
Make-up water, preheated by sec heat		357	85	
Turbine cond., preheated by sec heat		357	85	
Feedwater to boilers		609	143	
HP-steam		3400	515	110.0
MP2-steam, desuperheated		2944	275	25.0
MP-steam, desuperheated		2814	195	9.0
LP-steam, desuperheated		2738	144	3.0
Mech./el efficiency turbine	-	0.97		
Dry solids to recovery boiler	t/d	5869		
Net useful heat from liquor	MW	685		
Bark fuel from wood yard	DS t/d	1028		
from that to lime kiln	DS t/d	-276		
sold bark	DS t/d	0		
sludge etc, as wood fuel	DS t/d	0		
bark to power boiler	DS t/d	-752		
Net useful heat from fuel in bark boiler	MW	146		
	ADt/d			
Produced pulp, MCR	4000			
of which softwood	0			
of which hardwood	4000			
Market pulp	4000			

STEAM CONSUMPTION	Steam Flow t/h	Temp °C	Condensate Flow t/h	Heat Effect MW
HP-steam				
Back-pressure turbine				155.4
MP2-steam	(126.3)			
MP-steam	(239.4)			
LP-steam	(477.7)			
Condensing turbine				336.9
condensing steam	381.1	35	381.1	
Direct reduction HP-MP	(0.0)			
Direct reduction HP-LP	(0.0)			
Soot blowing recovery boiler	0.0		0.0	0.0
Blow down recovery boiler	5.1		0.0	1.9
Soot blowing bark boiler	0.0		0.0	0.0
Blow down bark boiler	1.0		0.0	0.4
Total HP-steam	387.2		381.1	494.6
MP2-steam				
Soot blowing recovery boiler	51.2		0.0	41.0
Air preheater recovery boiler	29.3	160	29.3	(18.5)
Feedwater interheater, recovery boiler	49.3	200	49.3	(28.8)
Soot blowing power boiler	2.0		0.0	1.6
Total MP2-steam	131.9		78.6	42.6
MP-steam				
Air preheater recovery boiler	36.8	170	36.8	(21.4)
Air preheater bark boiler	7.0	170	7.0	(4.1)
Feedwater preheater, recovery boiler	68.8	180	68.8	(39.3)
Digesting	83.3	170	0.0	63.7
Bleaching	3.3	180	0.0	2.5
Oxygen stage	5.0	100	0.0	3.8
Evaporation	27.3	140	25.9	17.1
Chemical preparation	1.7	100	0.0	1.3
Miscellaneous, losses	7.2	100	2.2	5.3
Total MP-steam	240.4		140.6	93.7
LP-steam				
Air preheater recovery boiler	2.4	148	2.4	(1.4)
Air preheater bark boiler	10.0	148	10.0	(5.9)
Woodyard	0.0		0.0	0.0
Digesting	0.0		0.0	0.0
Bleaching	31.7		0.0	23.5
Pulp machine	146.3	100	131.7	95.7
Evaporation	176.2	140	167.4	106.6
Hot water production	0.0	130	0.0	0.0
Chemical preparation	5.0	100	4.0	3.3
Causticising	0.0	100	0.0	0.0
Heating etc	0.0	100	0.0	0.0
Blow off	0.0	100	0.0	0.0
Miscellaneous, losses	11.5	100	3.4	8.2
Steam to feedwater tank	78.4		78.4	
Total LP-steam	461.5		397.3	237.3

SUMMARY STEAM CONSUMPTION	Flow t/h	Temp °C	Flow t/h	Effect MW
HP-steam	387.2		381.1	494.6
MP2-steam	131.9		78.6	42.6
MP-steam	240.4	168	140.6	93.7
LP-steam	461.5	123	397.3	237.3
Make-up water			223.2	
TOTAL STEAM CONSUMPTION	1221.0		1221.0	868.2

STEAM PRODUCTION		Steam Flow t/h	Heat Effect MW
Recovery boiler	t/ADt		
HP-steam	6.14	1024.1	793.7
soot blowing		0.0	0.0
blow down		5.1	1.1
feedwater preheat MP			-39.3
feedwater preheat MP2, inter eco			-28.8
air preheating, LP-steam			-1.4
air preheating, MP-steam			-21.4
air preheating, MP2-steam			-18.5
Sum		1029.2	685.3
Extern överhettare			0.0
Bark boiler	t/ADt		
HP-steam	1.20	200.4	155.3
soot blowing		0.0	0.0
blow down		1.0	0.2
air preheating, LP-steam			-5.9
air preheating, MP-steam			-4.1
Sum		201.4	145.52
MP-steam from boilers (H2SO4)		0.0	0.0
desuperheating water MP2-steam		5.6	
desuperheating water MP-steam		1.0	
drainage water LP-steam		-16.2	
Secondary heat for preheating make-up water			37.3
TOTAL STEAM PRODUCTION		1221.0	868.2

POWER CONSUMPTION	kWh/ADt	MW
Wood yard	30	5.0
Digester	30	5.0
Washing and screening, O2 delignification	100	16.7
Bleaching	40	6.7
Pulp machine	115	19.2
Evaporation	30	5.0
Causticising, lime kiln incl.gasifier	25	4.2
Boiler house	105	17.5
Cooling tower etc	25	4.2
Raw water treatment and distribution	15	2.5
Effluent treatment	15	2.5
Chem preparation	20	3.3
Miscellaneous, losses	10	1.7
Sum	560	93.3
Sold power	1090	181.7
Total	1650	275.0
POWER PRODUCTION		
Back-presssure power	900	150.0
Condensing power	750	125.0
Bought power	0	0.0
Sum	1650	275.0

REFERENCE MILL FOR BLEACHED KRAFT MARKET PULP 2024

The purpose of this study was to update hypothetical “reference mills”, representing the state-of-the-art of pulp and paper production in the Nordic countries. These model mills have been developed in several versions going back all the way to the 1970s. The main emphasis has been on solutions which have affected energy use and electricity production. The reference mills have typically been used for benchmarking and for evaluating new process concepts in relation to the reference concept.

This report describes mills that produce dried and bleached kraft pulp to be sold on the market. The mills would be self-sufficient in both power and steam with only the recovery boiler and back pressure turbine. The mills have a power boiler to make use of surplus bark and wood waste, and for sludge recovery. There is an excess of steam from the recovery and power boilers which is utilized in a condensing turbine to produce renewable power for export.

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