A Case Study on the Effects of Lignin Recovery on Recovery Boiler Operation

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3 authors, including:

Erkki Välimäki
Valmet Technologies Oy

A Case Study on the Effects of Lignin Recovery on Recovery Boiler Operation

Erkki Välimäki, Piia Niemi and Kari Haaga
Metso Power Oy, Box 109, FI-33101 Tampere, Finland

ABSTRACT

Lignin recovery from the black liquor of a pulp mill has become an attractive process option. Burning lignin lean black liquor may in some cases clear the way for mill capacity increase. Lignin can be combusted with higher efficiency in a power boiler or used as a fuel to substitute fossil fuel in a lime kiln. Lignin recovery and further refining to transportation fuels or specialty chemicals is also seen as a part of many potential biorefinery platforms.

The effects of lignin recovery used as a means for mill capacity raise in a modern hardwood pulp mill case are evaluated as a table top study. The operational limits of the recovery boiler and the overall operation of the recovery process of the mill are of interest in the evaluation. Depending on the approach, lignin recovery maximum is limited either by the combustion conditions in the recovery boiler or by the smelt production for further processing at the white liquor plant.

In the studied mill, with approximate lignin recovery rate of 0.16 t lignin per ADt pulp, the mill capacity can be raised from 1.0 MADt/year to targeted 1.25 MADt/year. The amount of the separated lignin, with this rate, is more than sufficient to replace the fossil fuel used in the lime kiln.

INTRODUCTION

In case of pulp mill capacity raise the recovery boiler is quite often the process bottleneck. Some of the boilers are originally designed for an upgrade to higher capacity. This is an expensive option and in many cases this possibility has been already used. A new approach for increasing mill capacity is lignin recovery from the black liquor for the purpose of decreasing the heat content of the liquor. LignoBoost process of Metso is developed for this purpose and the process is capable of recovering up to 70% of the black liquor lignin.

Lignin content of the softwood and hardwood differ from each other significantly. Typical lignin contents given in the literature are 30% in SW and 20% in HW [1, 2, 3]. It is estimated that the lignin content of the softwood black liquor is approximately 510 kg/ADt of pulp. The respective value for the hardwood black liquor is 340 kg/ADt of pulp [4]. This results in 50% higher potential for lignin recovery from softwood than from hardwood. The difference of the pulping raw materials has an effect on the lignin recovery process design and operational conditions. In both cases up to 25% increase in mill capacity can be expected when utilizing the black liquor lignin separation.

When studying the effect of the lignin recovery on the recovery cycle several parameters have to be considered. Most important parameters are the black liquor properties like heating value and dry solids content. Another important parameter is the heat load into the boiler. Heat load is reduced when lignin is recovered and the black liquor mass flow rate can be increased in order to reach constant heat input.

Lignin recovery has been studied earlier in case of softwood kraft pulp mill [4, 5]. In this study the mill is a modern eucalyptus kraft pulp mill with the capacity of one million air dry metric tons per year. The machinery of the mill was originally dimensioned for future 25% capacity increase which makes the mill an interesting case from the lignin recovery point of view. The capacity raise of the recovery boiler was originally planned to be achieved by additional superheater. Utilizing the lignin recovery process offers another option for this goal.

RECOVERY ISLAND

The recovery island of the mill is designed to support an annual production of one million air dry metric tons of bleached pulp on Eucalyptus with a provision for further capacity increase up to 1.25 million tons per year. A flow scheme of the recovery island is shown in figure 1.

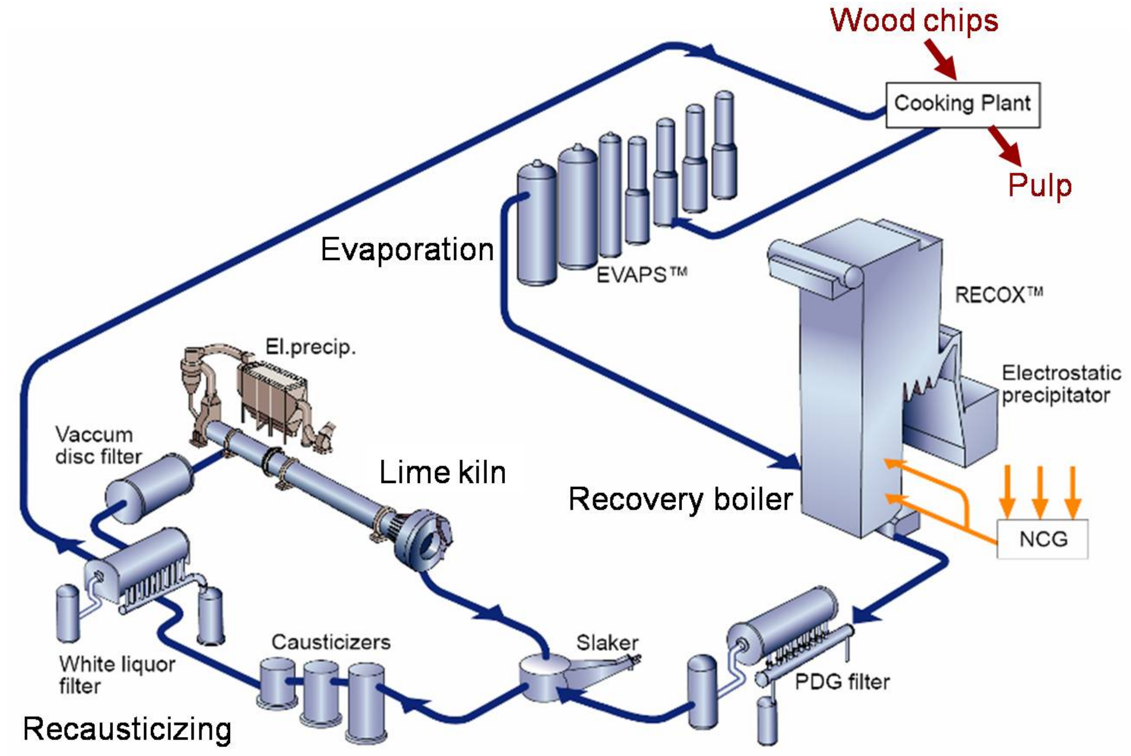

Figure 1. Recovery island of the mill.

Capacities of the recovery island main equipment are shown in table 1.

Table 1. Capacities of the recovery equipment.

Process	Units	Rate
Evaporation	tH_2O/h	1100
Recovery boiler	tDS/d (virgin)	4700
Recausticizing	m^3/d	10000
Lime kiln	tCaO/d	900

In this mill the weak black liquor from the cooking plant is evaporated in a 6-effect evaporation plant to produce black liquor high dry solids of 80%. The concentrated black liquor is stored in the pressurized liquor tanks and sent to the recovery boiler where chemicals used in the cooking process are recovered and the heat resulting from the recovery process is converted into steam energy. The chemical smelt that flows from the furnace is dissolved into weak wash forming green liquor. The green liquor is fed into the white liquor plant to be processed further into white liquor for the cooking process. The white liquor plant consists of a lime kiln and modern recausticizing plant using filtration techniques.

RECOVERY BOILER

Black liquor from the evaporation plant is combusted in the recovery boiler. How the recovery boiler is dimensioned mainly depends on the yield of the wood raw material. Variation in raw material quality may cause variation on the heating value and dry solids content of the black liquor. The steam generation of the recovery boiler is determined by the black liquor dry solids capacity. It is also affected by the heating value and dry solids content of the black liquor.

The side view of the studied recovery boiler is shown in figure 2.

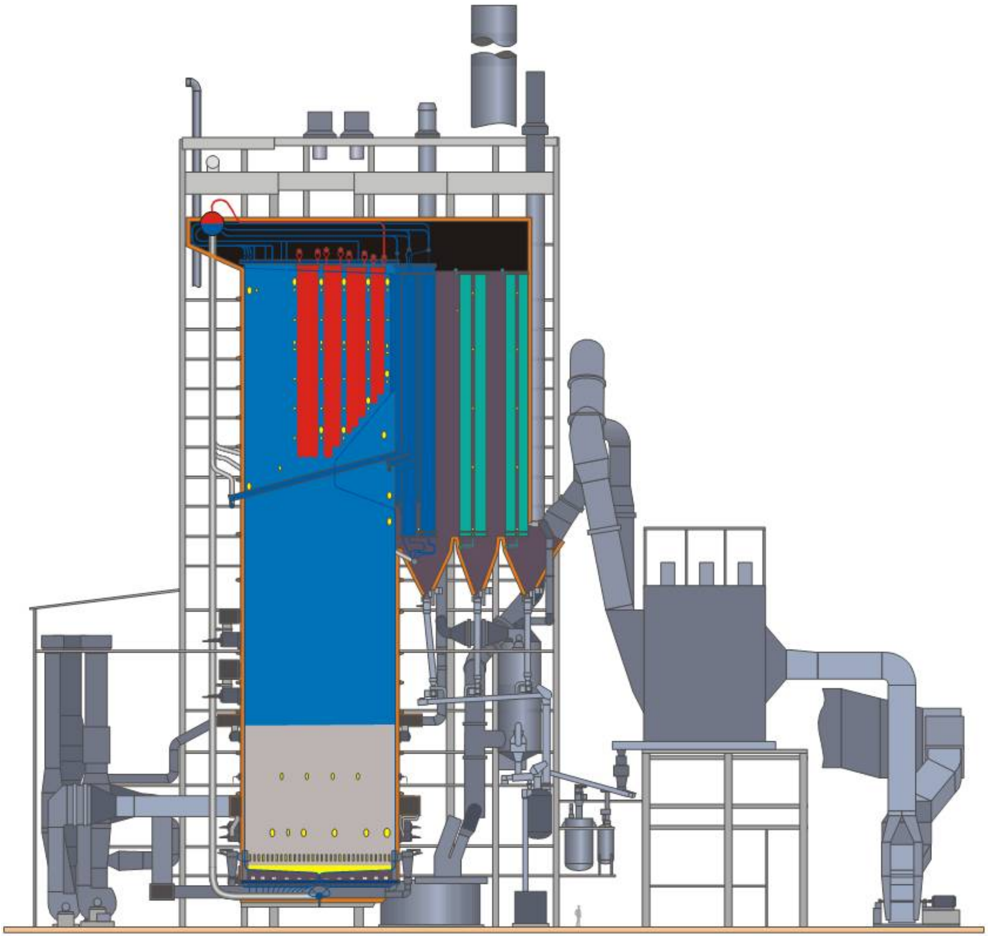

Figure 2. Side view of the studied recovery boiler.

The studied boiler is designed for 4700 tDS/d, having a steam production of 205 kg/s, and 85 bar, 480 °C steam parameters. The design dry solids content of the black liquor is 80% and the design higher heating value 14.00 MJ/kgDS. In addition to burning black liquor the recovery boiler is also designed to burn all the vent gases from the smelt dissolving and weak odorous gases from the fiberline, evaporation plant, and recausticizing plant. The strong odorous gases and the liquefied methanol from the methanol plant are also burnt in the recovery boiler through a separate burner located in the secondary air level. A torch serves as a stand-by burner in case the strong gases cannot be burned in the boiler. Despite the multi-fuel burning concept, with good control of the boiler combustion, the boiler operates according to design and below the TRS and SO_2 emission limits.

The boiler is furnished with ash leaching process for removing the non process elements, potassium and chloride, from the mill cycle. Provisions for the recovery boiler, e.g. adding a new superheater stage, has been made to take the boiler load up to 5500 tDS/d, giving extra recovery capacity for higher bleached pulp production up to 1.25 MADt/year.

METHODOLOGY

For recovery boiler studies the analysis of the black liquor in correlation to lignin recovery percentage is calculated. For this purpose an excel spreadsheet has been developed. Elemental analyses with higher heating values of the original virgin black liquor and lignin are given as input information for the spreadsheet calculation. Also the initial lignin content of the black liquor is given as an input figure. Lignin recovery percentage is given as a variable into the calculation. Based on the input information, a number of quantities are calculated, as a function of lignin recovery percentage.

The calculated quantities are:

1) The elemental analysis of the lignin lean black liquor
2) The higher heating value of the lignin lean black liquor
3) The mass flow rate and heat value of the recovered lignin
4) Three different predictions for black liquor dry solids mass flow rates from cooking and into the boiler, and respective pulping capacities, being:
    1. lignin recovered, no other adjustment into black liquor flow rate
    2. lignin recovered, black liquor dry solids mass flow rate into the recovery boiler maintained
    3. lignin recovered, heat load into the recovery boiler maintained unchanged

The calculation is done using the nominal values for the black liquor:

- HHV 14.00 MJ/kgDS
- DS 80%

It is well known that these are not invariable properties even if the raw material for cooking comes from the same source. In addition to nominal values, a heating value prediction is done for the virgin black liquor HHV, using the elemental analysis and a mathematical correlation developed for the purpose. The correlation is based on the multi variable analysis using the values of carbon, hydrogen, sulfur, oxygen and sodium contents of the black liquor. Metso's black liquor databank with close to one thousand analyses was used for establishing the correlation.

The prediction by correlation resulted in HHV 13.425 MJ/kgDS when the elemental analysis of the design black liquor is used as basis for the prediction. Both nominal and predicted HHV values are used in recovery boiler studies. Also the dry solids content of the black liquor is varied, having values 70%, 75% 80% and 85%, for the recovery boiler studies.

Because the boiler is furnished with the ash leaching system for removing the non process elements, potassium K and chloride Cl, low values for these constituents are used in the black liquor elemental analysis, 0.5% for K and 0.6% for Cl.

Using the given input data Metso's recovery boiler designer program, RBD, is used for the studies. When doing boiler calculations two basic principles are followed.

1) The pulping capacity of the mill is not limited by the recovery boiler when using the highest black liquor dry solids content, 85%. Instead the same dry solids load into the boiler is used as for 80% dry solids content. This naturally results in higher steam generation.
2) When using the predicted HHV 13,425 MJ/kgDS the boiler steaming rate is maintained by increasing the solids flow into the boiler respectively.

EFFECTS OF LIGNIN RECOVERY

Removing lignin from the black liquor results in decreasing organic part of the black liquor dry solids. This in turn has an influence on the combustion properties of the black liquor especially by decreasing the heating value of the fuel. The deterioration is stronger in softwood than in hardwood case because of the differencies in the lignin contents and heating values of the lignin in black liquor.

Effect on Black Liquor Analysis

The lignin content of the black liquor dry solids is estimated to be 21% at the starting point, without any lignin recovery. The elemental analyses of the original virgin black liquor and lignin are shown in table 2. Table 3 in turn shows the change in black liquor analysis when lignin is recovered in increasing rates.

Table 2. Analyses of black liquor and lignin.

		Black Liquor	**Lignin**
HHV (nominal)	MJ/kg_{DS}	14.000	25.400
HHV (predicted)	MJ/kg_{DS}	13.425	25.400
C	w-%	34.50	62.50
H	w-%	3.20	5.60
S	w-%	3.80	2.50
O	w-%	35.30	29.15
N	w-%	0.10	0.15
Na	w-%	22.00	0.10
K	w-%	0.50	0.00
Cl	w-%	0.60	0.00
Total	w-%	100.00	100.00

Table 3. Changing virgin black liquor analysis with increasing lignin recovery.

Lignin recovery		**0 %**	**10 %**	**20 %**	**30 %**	**50 %**	**70 %**
HHV	MJ/kg_{DS}	14.000	13.756	13.500	13.234	12.663	12.035
HHV	MJ/kg_{DS}	13.425	13.168	12.900	12.620	12.020	11.361
C	w-%	34.50	33.90	33.27	32.62	31.22	29.67
H	w-%	3.20	3.15	3.09	3.04	2.92	2.79
S	w-%	3.80	3.83	3.86	3.89	3.95	4.02
O	w-%	35.30	35.43	35.57	35.71	36.02	36.36
N	w-%	0.10	0.10	0.10	0.10	0.09	0.09
Na	w-%	22.00	22.47	22.96	23.47	24.57	25.77
K	w-%	0.50	0.51	0.52	0.53	0.56	0.59
Cl	w-%	0.60	0.61	0.63	0.64	0.67	0.70
Total	w-%	100.00	100.00	100.00	100.00	100.00	100.00

Black liquor elemental analyses and heating values shown in table 3 are used in all recovery boiler calculations.

Effects on Recovery Boiler Operation

When lignin is recovered, the heating value of the black liquor decreases. This results in lower heat load into the boiler unless the black liquor flow rate is controlled respectively. Herewith lignin recovery offers an opportunity to either debottleneck the recovery boiler or an opportunity to increase the pulping capacity of the mill.

When evaluating the operational conditions of the recovery boiler, with lignin recovery, parameters well describing the combustion prerequisites are the heart heat release rate, HHRR, and adiabatic combustion temperature, Tad. To assure stable and intense combustion of the black liquor recommended lowest limiting values for these properties used in this study are, HHRR 2.50 MW/m^2, Tad 1450 °C. In this case HHRR means the minimum design value at the maximum boiler capacity when lignin is recovered.

Table 4 shows the most essential calculated quantities of the recovery boiler operation when lignin is recovered. For these numbers nominal HHV value of 14.00 MJ/kgDS is used for calculation of these figures. The respective values in case where the predicted HHV 13,425 MJ/kgDS is used are shown in table 5. In these two boiler calculations the dry solids content of the black liquor is 80%; no other adjustment is applied on the black liquor flow rate, other than the lignin recovery. This manner of lignin recovery and boiler operation has no effect on mill capacity or recovery cycle operation assuming that a proper chemical recovery and sulfur reduction rate can be maintained. In all boiler calculations the steam parameters of the boiler are maintained at values 480 °C and 85 bar. For flue gas and combustion air calculations air ratio with excess air coefficient $\lambda = 1.15$ is used.

Table 4. Operation of the recovery boiler with lignin recovery, DS 80-%, HHV 14.00 MJ/kg.

Lignin recovery		**0%**	**10%**	**20%**	**30%**	**50%**	**70%**
BL into Boiler	t_{DS}/d	4700	4601	4503	4404	4207	4009
HHRR	MW/m^2	3,03	2,92	2,80	2,69	2,45	2,22
T - Adiabatic	°C	1738	1731	1726	1718	1702	1682
Steam Mass Flow	kg/s	205	195,9	187,0	178,1	160,5	142,7
Furnace Exit	°C	1026	1011	995	977	941	900
Primary SH out	°C	578	569	559	548	528	506
Boiler Bank out	°C	418	412	406	400	388	376
Economizer 1 out	°C	156	155	154	152	150	148
Total attemperation	°C	36	33	30	27	19	7
SH Pressure Drop	bar	9,8	9,1	8,4	7,7	6,4	5,2
Flue Gas	m^{3}n/s	238	228	219	211	192	174
Flue Gas	m^{3}n/kg_{DS}	4,377	4,299	4,214	4,131	3,948	3,746
Combustion Air	m^{3}n/s	193	184	176	168	151	135
Combustion Air	m^{3}n/kg_{DS}	3,542	3,464	3,380	3,297	3,115	2,913
Smelt Mass Flow	kg/s	26,4	26,4	26,4	26,4	26,5	26,5

Lignin recovery results in decrease of the black liquor dry solids mass flow into the boiler furnace. The heart heat release rate is decreasing, even faster than the black liquor mass flow rate, because the heating value of the removed lignin is much higher than the respective value of the rest of the black liquor. By this operating mode, lignin recovery is limited to 50% in maximum, with the HHRR being considered as a limiting index.

Because of the lowering heat input the steam generation is decreasing respectively. 20% of steam generation is lost with the maximum allowable lignin recovery (50%). When organic matter is removed from the black liquor the air and flue gas quantities per kgDS of the black liquor are decreasing. In this study as well as in our earlier study [5] in a softwood pulp mill case, the variables remain in the area which is typical for black liquors in general. It can be expected that no change in air and flue gas fans or their control is needed.

The analyses of the black liquor samples received from the studied mill have shown that the HHV of the liquor may vary downwards from the design value 14.00 MJ/kgDS. That is why another boiler calculation is performed using the predicted HHV 13.425 MJ/kgDS. Black liquor flow rate at the starting point is fitted to match with the design steam generation.

Table 5. Operation of the recovery boiler with lignin recovery, DS 80-%, HHV 13.425 MJ/kg.

Lignin recovery		**0%**	**10%**	**20%**	**30%**	**50%**	**70%**
BL into Boiler	t_{DS}/d	4975	4871	4766	4662	4453	4244
HHRR	MW/m^2	3,08	2,96	2,83	2,71	2,47	2,22
T - Adiabatic	°C	1665	1656	1647	1635	1611	1581
Steam Mass Flow	kg/s	205	195,7	186,4	177,0	158,3	139,5
Furnace Exit	°C	1012	997	980	962	923	879
Primary SH out	°C	585	575	564	534	533	510
Boiler Bank out	°C	423	417	411	404	392	379
Economizer 1 out	°C	159	158	156	155	153	150
Attemperation	°C	39	36	33	30	22	12
SH Pressure Drop	bar	9,8	9,0	8,3	7,5	6,2	4,9
Flue Gas	m^{3}n/s	251	242	232	222	203	183
Flue Gas	m^{3}n/kg$_{DS}$	4,363	4,284	4,199	4,116	3,932	3,729
Combustion Air	m^{3}n/s	204	195	186	178	160	143
Combustion Air	m^{3}n/kg$_{DS}$	3,540	3,462	3,378	3,295	3,112	2,911
Smelt Mass Flow	kg/s	27,9	28,0	28,0	28,0	28,0	28,1

The calculation shows that recovery boiler parameters, of this operating mode, do not differ too much from the quantities of the previous calculation. Also, with the lower HHV value 13.425 MJ/kgDS, up to 50% lignin recovery seems to be achievable.

Constant heat load into the boiler

In constant heat load operating mode lignin is recovered from the black liquor as earlier, but now black liquor flow rate is controlled to maintain the constant heat flow into the boiler furnace. Boiler calculation for this case is performed under same condition (DS, HHV) as in previous case. Results of these calculations are shown in tables 6 and 7.

Maintaining constant heat load, when lignin is recovered, requires increasing black liquor flow rates into the boiler. This in turn results in increasing mill capacity, unlike in the previous calculation, where lignin was recovered but the dry solids flow into evaporation was maintained in a constant value.

Calculated values in table 6 show that with the nominal HHV 14.00 MJ/kgDS the limiting index is neither HHRR nor adiabatic temperature, but the mass flow rate of the smelt out of the boiler. The machinery of the recovery process is designed to support an annual production of one million air dry metric ton of pulp with a provision for further capacity increase up to 1.25 million tons per year. If 25% increase also in smelt flow out of the boiler furnace is accepted to be treated at the white liquor plant, the maximum for smelt flow is 33 kg/s. Table 6 shows that this flow rate is met approximately at the point where lignin is recovered at 50% rate. In case of the lower HHV (13.435 MJ/kgDS) this limiting flow rate is met at a little lower lignin recovery rate, as can be seen in table 7.

When heat load is maintained the loss in steam generation is mainly caused by the additional heat loss of smelt. At the maximum lignin recovery rate the steam generation drops only 2 – 3% as can be seen from tables 6 and 7.

Table 6. Operation of the recovery boiler with lignin recovery, constant heat load, DS 80%, HHV 14.00 MJ/kg.

Lignin recovery		**0%**	**10%**	**20%**	**30%**	**50%**	**70%**
BL to EVAPS	t_{DS}/d	4700	4886	5088	5307	5806	6409
BL into Boiler	t_{DS}/d	4700	4784	4874	4972	5196	5467
HHRR	MW/m^2	3,03	3,03	3,03	3,03	3,03	3,03
T - Adiabatic	°C	1738	1732	1728	1721	1708	1692
Steam Mass Flow	kg/s	205	203,6	202,3	201,0	197,9	194,3
Furnace Exit	°C	1026	1023	1020	1017	1009	1000
Primary SH out	°C	578	577	576	574	571	567
Boiler Bank out	°C	418	417	416	415	414	411
Economizer 1 out	°C	156	156	156	156	156	156
Attemperation	°C	36	36	36	36	36	35
SH Pressure Drop	bar	9,8	9,7	9,6	9,5	9,2	8,9
Flue Gas	m^3n/s	238	237	237	236	234	232
Flue Gas	m^3n/kg_{DS}	4,377	4,289	4,193	4,100	3,893	3,664
Combustion Air	m^3n/s	192	192	190	189	187	184
Combustion Air	m^3n/kg_{DS}	3,532	3,462	3,377	3,292	3,106	2,901
Smelt Mass Flow	kg/s	26,4	27,5	28,6	29,9	32,7	36,2

Table 7. Operation of the recovery boiler with lignin recovery, constant heat load, DS 80%, HHV 13.425 MJ/kg.

Lignin recovery		**0%**	**10%**	**20%**	**30%**	**50%**	**70%**
BL to EVAPS		4795	5181	5404	5648	6208	6892
BL into Boiler	t_{DS}/d	4975	5072	5177	5292	5556	5879
HHRR	MW/m^2	3,08	3,08	3,08	3,08	3,08	3,08
T - Adiabatic	°C	1665	1657	1649	1638	1617	1590
Steam Mass Flow	kg/s	205	203,8	202,3	200,9	197,3	192,9
Furnace Exit	°C	1013	1009	1005	1001	991	979
Primary SH out	°C	585	584	582	581	577	573
Boiler Bank out	°C	423	422	421	421	419	417
Economizer 1 out	°C	159	159	159	159	159	159
Attemperation	°C	39	39	39	39	39	39
SH Pressure Drop	bar	9,8	9,7	9,6	9,4	9,1	8,7
Flue Gas	m^3n/s	251	251	250	250	249	248
Flue Gas	m^3n/kg_{DS}	4,363	4,274	4,179	4,085	3,877	3,649
Combustion Air	m^3n/s	204	203	202	202	200	197
Combustion Air	m^3n/kg_{DS}	3,540	3,461	3,375	3,290	3,104	2,899
Smelt Mass Flow	kg/s	27,9	29,1	30,4	31,8	35,0	38,9

Effect of black liquor dry solids content variation

Effect of lignin recovery on recovery boiler operation is evaluated using varying dry solids content of the black liquor in calculations. The effect of decreasing dry solids content on adiabatic combustion temperature is shown in figure 3 for the black liquor with the predicted HHV 13.425 MJ/kgDS. The black liquor with HHV 14.00 MJ/kgDS has naturally somewhat higher adiabatic temperatures.

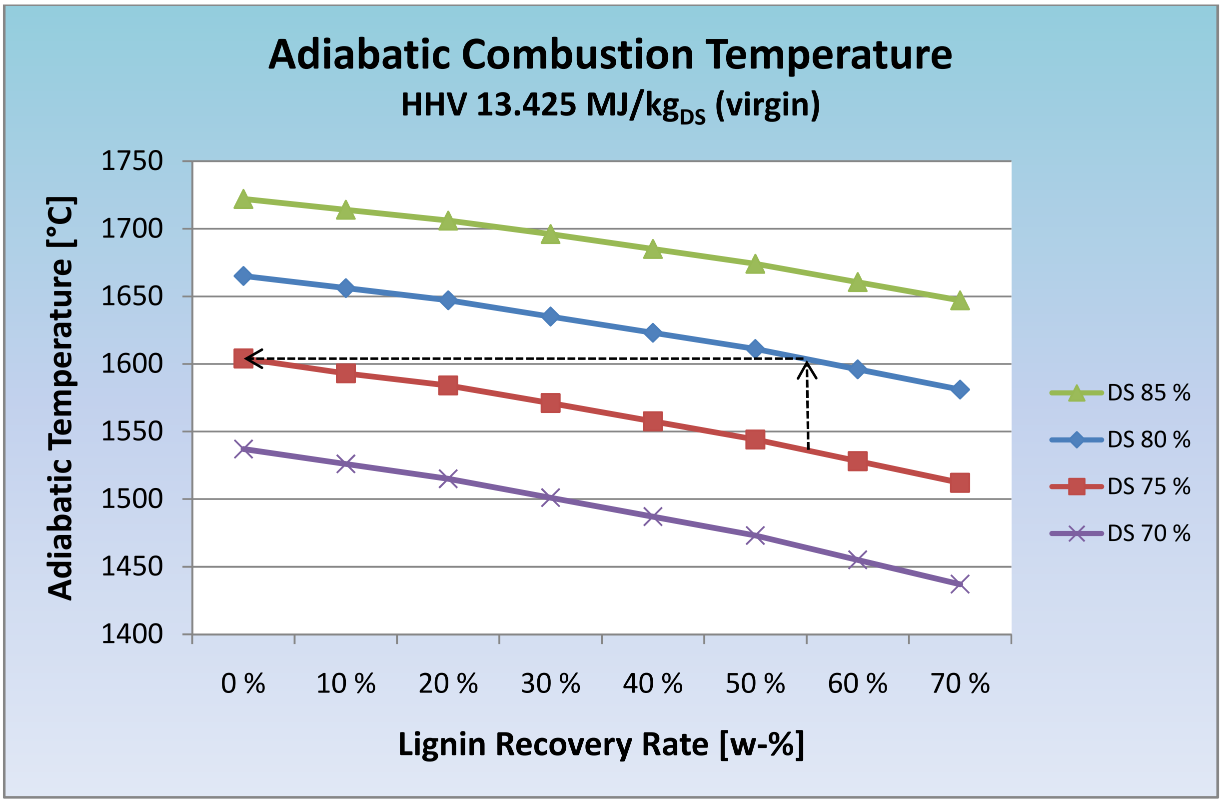

Figure 3. Effect of decreasing black liquor dry solids content on adiabatic combustion temperature.

The adiabatic combustion temperature is dependent on the black liquor heating value and dry solids content. When lignin is recovered the adiabatic temperature decreases with the heating value. With lower dry solids contents more water has to be evaporated and lower dry solids also results in lower adiabatic temperature. All in all, with the Eucalyptus black liquors evaluated in this study there is no problem of too low adiabatic temperatures. Only the more or less theoretical points with the highest lignin recovery rate and the lowest dry solids content of the black liquor are located around the limit value 1450 °C as can be seen in the figure 3.

Figure 3 shows that at the lignin recovery rate of 55% an increase of 5% in black liquor dry solids content restore the adiabatic combustion temperature of the studied liquor back to the original value. With lower lignin recoveries this takes place even with lower increase in dry solids. This is an important finding especially for the boilers burning black liquor with clearly lower heating value and with low dry solids content. In such cases lignin recovery results in too low combustion temperature, and an increase in the dry solids content is necessary to achieve intense and stable combustion of the black liquor.

Effect on Pulp Mill Capacity

Lignin recovery from the black liquor clears the way for higher dry solids loads into the recovery boiler. This in turn facilitates the pulp mill capacity increase. If the heat load into the boiler is maintained, when lignin is recovered in increasing rate, mill capacity is increasing with the lignin recovery percentage.

The effect of the lignin recovery on the mill capacity, in this study case, is shown in figure 4. The calculation is done with four different black liquor dry solids contents, 70%, 75%, 80%, and 85%. In each calculation the initial mill capacity, with 0% lignin recovery, is based on the nominal steam generation of the recovery boiler with different black liquors. The nominal values are 205 kg/s, 480 °C, and 85 bar. With lower dry solids contents, maintaining the nominal steam generation 205 kg/s initially, results in higher dry solids mass flow rates, and respectively slightly higher mill capacities. Higher inorganics load into the boiler in turn results in slightly lower steam generation, caused by increased loss of heat in smelt, even though the heat load into the boiler is maintained.

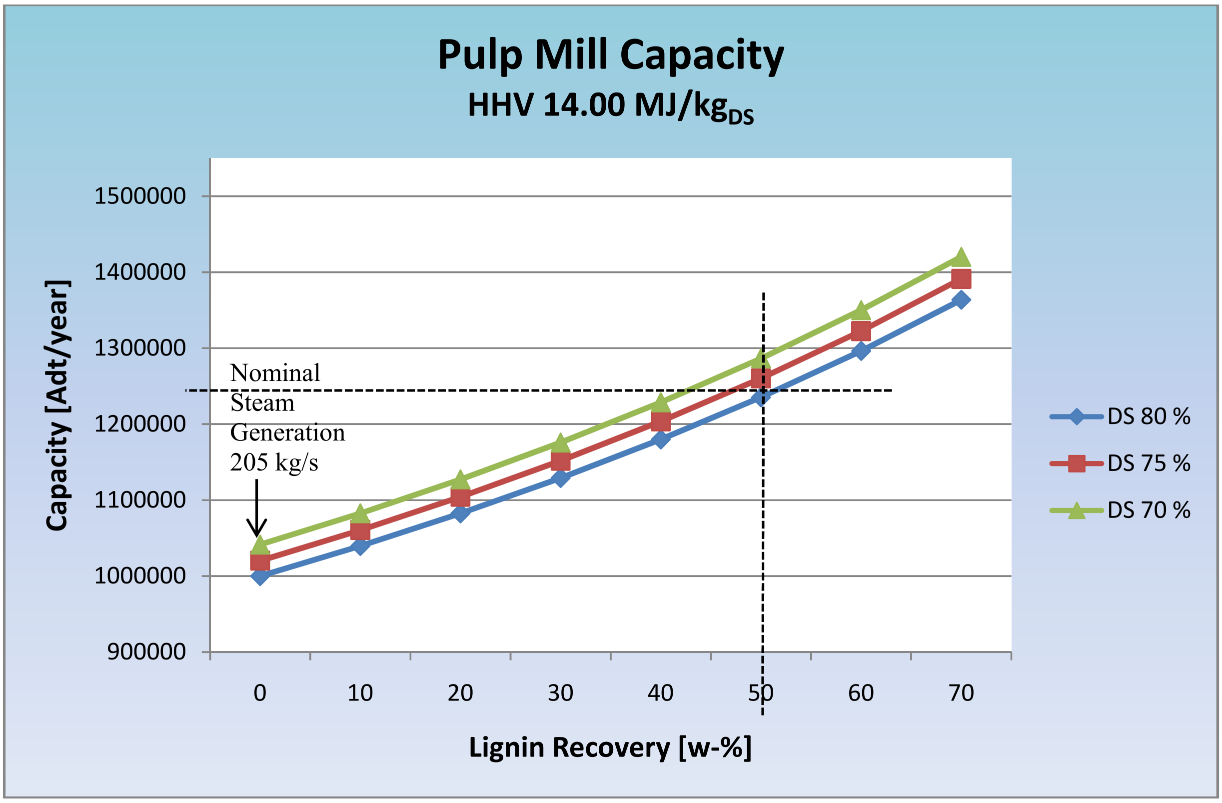

Figure 4. Effect of increasing lignin recovery on the pulp mill capacity.

Figure 4 shows that with the lignin recovery approximately of 50%, corresponding to 0.17 kg lignin per ADt of pulp, the mill capacity would increases to around 1.25 MADt/year. The exact number depends on the dry solids content of the black liquor when heat load into the boiler is the same with different black liquors on each lignin recovery rate.

Recovered Lignin

Recovered lignin can be burned with higher efficiency in a power boiler or used as a fuel to substitute fossil fuel in a lime kiln [6, 7, 8]. Lignin recovery and further refining to transportation fuels or high value chemicals can be seen in the future as a part of different potential cellulose based biorefinery platforms.

Currently lignin can be best exploited in energy use. When lignin is recovered the profit to pulp mill mainly comes from the capacity increase of the mill and added sales of pulp, less from lignin itself used as an energy replacement [9].

Mass flow of lignin recovered from the black liquor and respective heat power in lignin are shown in figure 6. Figure 7 shows energies recovered in lignin in relation to produced air dry ton of pulp and produced ton of lime in the lime kiln.

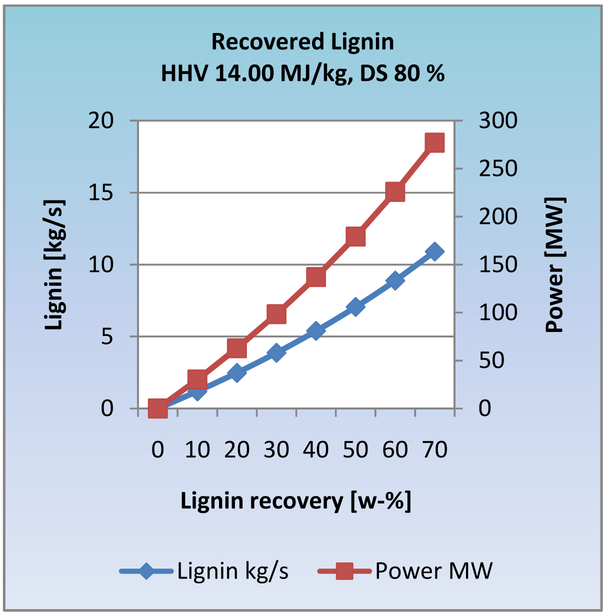

Figure 6. Recovered lignin mass and power.

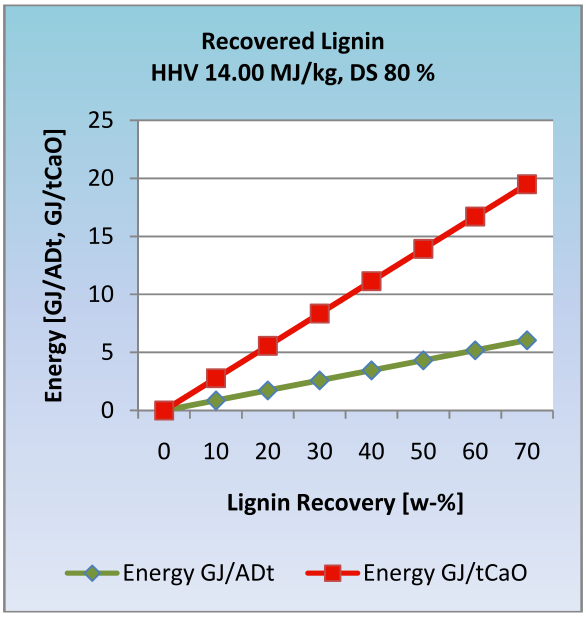

Figure 7. Recovered enery in GJ/ADt and GJ/tCaO.

If we consider that pulp mill capacity is increased to 1.25 MADt/year by recovering e.g. 50-% of lignin, corresponding to 0.17 t/ADt of pulp, the amount of energy recovered will be approximately 4.3 GJ/ADt or respectively 13.9 GJ/tCaO. If lignin is used to replace fossil fuel in lime kiln the recovered energy is more than sufficient for that purpose. Depending on the design the energy demand of a modern lime kiln operating at or near nominal capacity is in the range 5.5 - 6.5 GJ/tCaO [10]. The rest of the lignin, roughly 0.1 t/ADt, is available for burning in the power boiler or to be sold out of the mill.

CONCLUSIONS

The target of this work was to review the operational limits of the recovery boiler and the overall operation of the recovery process of the mill when lignin is recovered from the black liquor. The pulp mill of this case study is a modern Eucalyptus mill with one million air dry ton capacity.

As the rate of recovered lignin increases, boiler adiabatic combustion temperature (Tad) and heart heat release rate (HHRR) decrease. In this evaluation the HHV of the black liquor is rather high and therefore these are not actually any limiting indices. When lignin is recovered and no other adjustment is done on the black liquor flow rate HHRR is limiting the lignin recovery to 50% rate. With lower HHV this takes place even earlier, with lignin removal rate of 40%.

When lowering the HHV and dry solids of the black liquor, its adiabatic temperature declines as well even though the heat load into the boiler is maintained. A small raise in dry solids content of the black liquor is sufficient to restore the adiabatic temperature to its original level.

With lignin recovery rate of 50%, in the studied mill, the capacity can be increased from 1.0 MADt/year to targeted 1.25 MADt/year. The separated lignin is more than sufficient to replace the fossil fuel used in the lime kiln. Lignin recovery for capacity raise in one million ton Eucalyptus mill is a very attractive and realistic option as an alternative for recovery boiler upgrading to higher capacity.

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