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Energy savings combined with lignin extraction for production increase: case study at a eucalyptus mill in Portugal

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In previous research by the authors, energy savings combined with lignin extraction as a mean to debottleneck the recovery boiler were evaluated on a model mill. The study showed that this concept was a profitable alternative to recovery boiler upgrade. In the present paper the concept was taken one step further, and the potential for energy savings and possibilities for lignin extraction were evaluated at a real mill: a market pulp mill in Portugal. The energy-saving methods proved to be applicable also to the real mill and the steam-saving potential was 3.8 GJ/ADt or 30%. Lignin extraction trials with bench scale equipment showed that lignin extraction was fully viable at the studied mill. A full-scale lignin separation plant according to the LignoBoost concept, combined with energy savings was simulated in a computer environment and compared to installation of a new recovery boiler. A new recovery boiler had an investment cost four times higher than the LignoBoost concept including energy savings, but the electricity production would be higher. The profitability for a production increase of 16% was calculated for both cases. Steam savings combined with LignoBoost were found to have better profitability unless the electricity price is very high.

1. Introduction

Many kraft pulp mills have a desire to increase their production capacity. In such cases, the recovery boiler is often one of the major bottlenecks. To debottleneck the recovery boiler, lignin from the black liquor can be extracted, which decreases the load of the boiler in proportion to the lignin extraction. The extracted lignin, or other fuel, has to be burnt at the mill so as not to get a steam deficiency. This, and requires a biofuel boiler with sufficient over-capacity. Alternatively the steam demand of the process can be decreased. If the steam demand is decreased, part or even all of the extracted lignin is no longer needed for steam production and can instead be exported from the mill or used to replace fossil fuel in the lime kiln.

In a previous study on computer models of softwood kraft pulp mills, energy savings combined with lignin extraction turned out to be a profitable alternative to recovery boiler upgrade (Axelsson et al. 2006). The model mill was designed to resemble an average Scandinavian softwood mill as regards water usage and technological level. The model study showed that steam savings of 3.9 GJ/ADt or 23%

can be achieved by upgrading the evaporation plant and improving the heat integration via pinch analysis.

The purpose of the current paper was to take the concept of energy savings combined with lignin extraction one step further and evaluate the concept for a real mill. The mill studied was a eucalyptus pulp mill in Portugal which, in contrast to the model mill, is a hardwood mill. There are already several energy reduction studies of different real pulp mills (e.g. Fouche and Banerjee 2004, Bengtsson 2004) and some case studies of lignin extraction for production increase (e.g. Davy et al. 1991). The aims of this paper were to study energy-saving opportunities and their importance technically and economically in connection with lignin extraction and production increase in a hardwood pulp mill, to identify possible practical constraints in a real mill, and to compare the results with the corresponding ones from the softwood model mill.

In the model mill study, energy savings and lignin extraction were compared to upgrading the recovery boiler. Another important case is if the recovery boiler already is upgraded to its maximum point and a new recovery boiler is the only option. This is the case of the eucalyptus mill; hence, a new recovery boiler was assumed for comparison in the present paper.

2. Mill description

The studied mill is a market pulp mill producing bleached kraft pulp from eucalyptus hardwood. Key data for the mill can be found in Table I. For sufficient steam production, the mill is dependent on a biomass boiler where bark is burnt. The pulp production is 300,000 ADt/year, but it is desirable to increase the production to about 350,000 ADt/year or more. The largest bottleneck for increasing the pulp production is the recovery boiler.

3. Methods

A system analysis was carried out to evaluate the opportunities for energy savings and system consequences of lignin extraction. For the system analysis, a detailed full-mill model was created in the simulation software WinGEMS. With the model, we could get consistent mill pictures with and without lignin extraction or a new recovery boiler. For lignin extraction, the LignoBoost process was assumed (Öhman et al. 2006). The chemical consumption and yield for lignin extraction were based on bench scale trials at the mill where the LignoBoost concept was evaluated.

With stream data from the WinGEMS model, the heat integration opportunities were identified by applying pinch analysis in the same way as described in Axelsson et al. (2006). Besides heat integration, steam savings can be accomplished by introducing new equipment, e.g. an upgraded evaporation plant.

Table I: Key data of the eucalyptus mill.

Production	300 000	ADt/year
Digester yield	57	%
Hot and warm water	13.4	m^3/ADt
Water, total	34	m^3/ADt
Steam production	12.7	GJ/ADt
Recovery boiler	*10.7*	GJ/ADt
Biomass boiler	*2.0*	GJ/ADt
Electricity production	538	kWh/ADt
Electricity consumption	535	kWh/ADt

Table II: Solved pinch violations, steam savings and associated investments costs.

	Steam saving		Inv. cost		Piping	
	(GJ/ADt)	(MW)	k€	€/kW	k€	% of total
Recovery area 1	0.628	6.6	514	77	88	17
Evaporation plant	0.355	3.8	202	54	43	21
Bleach plant	0.342	3.6	400	111	60	15
Cooking	0.111	1.2	30	26	27	89
Heat recovery	0.229	2.4	254	105	113	45
Recovery area 2	0.386	4.1	555	136	79	14
Pulp dryer 1	0.190	2.0	319	159	0	0
Pulp dryer 2	0.142	1.5	153	102	60	39
TOTAL	2.4	25.2	2427	96	470	19.4

The investment costs associated with steam savings and lignin extraction were approximated in the same way as in Axelsson et al. (2006). Above this, a piping cost of 419 €/m was used in this real mill study. For the profitability analyses, annual earnings using the annuity method with annuity factors of 0.1 and 0.2 were used. The payback period was also calculated.

4. Steam reduction opportunities

A pinch analysis of the eucalyptus mill using a ΔT of about 5 K showed that, theoretically, the steam demand could be decreased by 3.3 GJ/ADt. Since solving all pinch violations gives a complex and expensive heat exchanger network, a suggestion on how 2.4 GJ/ADt can be solved is presented in Table II. An alternative to solving pinch violations would be to extract excess heat and use it in a process-integrated evaporation plant (Axelsson et al. 2006a). This option has a potential for higher steam savings and will be reported in a subsequent paper.

The piping cost for each solved pinch violation is presented separately in Table II and, as can be seen, it was 0-89% of the total cost for solving a pinch violation. The extreme values in the span relate to situations where either the existing piping or the existing heat exchangers could be used directly. On average, the piping cost was about 20% of the total cost, and hence no great discouragement to retrofitting the network.

A complementary measure that could save steam was to upgrade to a 7-effect evaporation plant, which would save 0.5 GJ/ADt of LP steam and give 0.3 GJ/ADt more HP steam if the concentration of the heavy liquor is increased from 69 to 74%. Additionally, 0.6 GJ/ADt of HP steam would be saved if new soot-blowing lances were installed. The potential for steam savings and the associated costs are summarized in Table III. When calculating in a case of production increase, it was assumed that all streams increase in accordance with the production increase. Consequently, we assumed that the specific saving potential was the same also in the case of production increase.

5. LignoBoost vs. new recovery boiler

For the production increase of 16%, two different approaches were compared: a new efficient recovery boiler, and lignin extraction with the LignoBoost concept; see Table IV. Energy savings by solving pinch violations according to Section 4 (2.4 GJ/ADt) were assumed in both approaches. With a new recovery boiler, energy savings gave incentives for a condensing turbine, which increased the electricity production. The electricity production also increased due to increased boiler efficiency and higher steam data with a new recovery boiler and a new back pressure-turbine.

Table III: Steam savings opportunities and associated costs.

	Savings		Investment cost	
	GJ/ADt	MW	M€	€/kW
Pinch violations	2.4	25.8	2.4	94
Soot blowing	0.59	6.3	0.08	13
Evaporation plant	0.8	8.5	10.9	1282
Tot.	3.8	40.6	13.4	330

To enable a production increase of 16% with the LignoBoost concept, about 88 kg lignin/ADt had to be extracted, which corresponds to 212 GWh/year. All the lignin could not be burnt in the biofuel boiler because of capacity limitations, and energy savings of at least 0.4 GJ/ADt were needed, which corresponds to a lignin export of 7500 ton dry lignin/year. With a fully utilized biofuel boiler and energy savings of 2.4 GJ/ADt there were incentives for a condensing turbine also in the case of lignin extraction. As an alternative to a condensing turbine, the biofuel export could be maximized to 383 GWh/year, which requires export of both lignin and bark. Biofuel export of this magnitude, however, led to a loss in electricity production; see Table IV.

Using the figures in the table, the profitability of the two approaches was calculated. For lignin export, two different biofuel prices were used: 15 and 30 €/MWh. The higher price can be considered if biofuel replaces fuel oil in the lime kiln. Because of the high investment cost, the payback period for a new recovery boiler was always higher than any LignoBoost alternative (not shown here). Looking at annual earnings and using an annuity factor of 0.1, the cases with lignin export were most profitable for electricity prices up to 50-80 €/MWh depending on the biofuel price; see Figure 4. With higher electricity prices, it can be more profitable to burn the lignin in the bark boiler and produce electricity in a condensing turbine. With an electricity price above 80 €/MWh, the approach with a new recovery boiler was the most profitable one. With an annuity factor of 0.2, the electricity price had to be about 160 €/MWh before the recovery-boiler alternative had the highest annual earnings (not shown here). This is an unrealistically high price.

Table IV: Key data for the LignoBoost process and the new recovery boiler for an increase of the pulp production from 300,000 ADt/Year to 350,000 ADt/year.

	LignoBoost process	New recovery boiler
Used recovery boiler	Existing boiler	New boiler (10% higher efficiency)
Operating cost/maintenance	0.9 M€/year	Same as current boiler
Steam data	69 bar, 445°C	92 bar, 490°C
Lignin extraction	88 kg/ADt	-
Total energy in extracted lignin	212 GWh/year	-
Steam savings of 2.4 GJ/ADt used for:		
A) Electricity production		
Investment cost	14 M€	88 M€
Lignin export	49 GWh/year	-
Back-pressure turbine	174 GWh/year	208 GWh/year
Condensing turbine	70 GWh/year	125 GWh/year
B) Biofuel export		
Investment cost	9.3 M€	-
Lignin and bark export	383 GWh/year	-
Back-pressure turbine	139 GWh/year	-

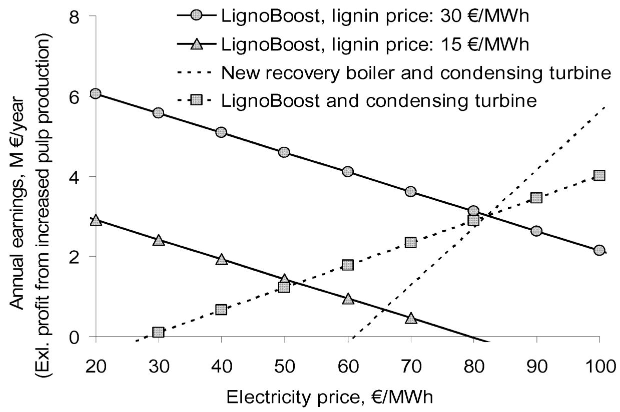

Figure 4: Profitability for a new recovery boiler and the LignoBoost concept.

6. Discussion and comparison with the model mill study

The model mill investigated previously (Axelsson et al. 2006) and the eucalyptus mill differed in process equipment, process design and raw material. In the end, the energy savings were almost the same, even though the measures for heat integration differed. The main reason for the difference is the existence of a pre-evaporation plant in the eucalyptus mill. If the pre-evaporation was removed, the measures for solving pinch violation would probably be similar in both mills. Possibly the saving potential would increase if the pre-evaporation were removed and if large parts of the water heating could be done with other sources (as in the model mill).

Another process difference is the condition of the recovery boiler. In the model mill it was assumed that the recovery boiler could be upgraded, which enabled higher electricity production. As in the present paper, the recovery boiler option was favoured by higher electricity prices. A new recovery boiler has 2-3 times higher investment cost than just upgrading the existing boiler. Consequently, higher electricity prices than in the model mill study were needed to give the same annual earnings as lignin extraction: about 80 €/MWh in this paper and about 55 €/MWh in the model mill study.

Energy savings in combination with lignin extraction should normally be very interesting. Without energy savings, and in the general case, a new biofuel boiler is needed so that the extracted lignin can be utilized for steam production. A new boiler would normally be considerably more expensive than the necessary energy savings. In the present paper we have shown that steam savings sufficient for a production increase of at least 16% are possible and the solutions were fully acceptable to mill personnel. With energy savings we would also come closer to sustainable pulp production.

In the special case of the studied eucalyptus mill, the existing biofuel boiler had a quite large overcapacity. Even so, a smaller supplementary boiler would be needed for the desired production increase. A small and simple boiler producing only LP steam is much cheaper than a biofuel boiler, but still more expensive than the necessary energy savings. In fact, energy savings that enable export of bark or lignin would normally be profitable by themselves, even though no additional boiler is needed, at least if the electricity production is not decreased from biofuel export. The opportunities for steam savings through process integration in connection with lignin extraction in production-capacity increase situations should therefore be both economically and environmentally advantageous. There is a potential for further energy savings which would enable larger bark export. The profitability for this opportunity was not calculated.

7. Conclusions

The conclusions from the case study of the eucalyptus market pulp mill where the potential for debottlenecking the recovery boiler by combining steam savings and lignin extraction using the LignoBoost concept has been investigated, are as follows:

- The approaches for saving steam and the tools used in the previous model mill study are also applicable to the real mill studied in this paper.
- There are good opportunities to reduce the steam demand in the studied mill: 3.8 GJ/ADt or 30%.
- Mill trials using bench scale equipment showed that lignin extraction according to the LignoBoost concept is fully viable in the studied mill.
- To debottleneck the recovery boiler for a production increase of 16%, 88 kg lignin/ADt lignin have to be extracted.
- Compared to a new recovery boiler, the LignoBoost concept has one fourth of the investment cost.
- A new recovery boiler has a higher potential for increased electricity production.
- LignoBoost shows better profitability than a new recovery boiler unless the electricity price is higher than 80 €/MWh.
- Energy savings in connection with lignin extraction can profitable by itself.

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