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Scandinavian Hardwood Biorefinery Using "Near-Neutral" Hemicelluloses Pre-extraction – Energy Efficiency Measures

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While in a conventional mill, the hemicelluloses and lignin fraction of the wood is burned in the recovery boiler to produce steam, in a biorefinery it can be used to produce added value products. In this paper, a comprehensive heat integration study for an average Scandinavian kraft model mill, as well as for a hemicelluloses extraction process with further utilization for ethanol production, is performed. The results show that when the total integration of the hemicelluloses utilization process with the mill is considered, the integrated biorefinery could become self-sufficient in terms of steam.

1. Introduction

Implementation of biorefinery concepts has the potential to strengthen the competitiveness of the pulp and paper industry by diversifying the products' mix. For example, a modern kraft mill can become a net exporter of green materials or energy, and in this way reduce the fossil dependency in other parts of the energy system. This paper describes the hemicelluloses pre-extraction and production of ethanol as an example of an added value product (referred to as "HC utilization process" in this paper). Hemicelluloses can be pre-extracted via various methods, e.g. near-neutral, alkaline, dilute acid and water extraction. Hemicelluloses extraction will affect the mill in different ways, for example, the severe conditions in water and dilute acid extraction can have a negative impact on the fibre properties. In contrast, it has been shown that, when using milder conditions, as in the near-neutral extraction method, hemicelluloses can be extracted while maintaining the quantity (i.e. pulp yield) and quality (e.g. tear index) of the pulp (Mao et.al, 2008). In addition to changes in pulp quality and quantity, extraction of hemicelluloses affects the energy balance of the mill, resulting in a steam deficit. The deficit could in principle be compensated by burning extra fuel at the mill. However, this could jeopardize the economic and environmental performance of the biorefinery. Alternatively, the steam demand can be reduced by increasing the energy efficiency via process integration. Many energy saving potentials in kraft pulp mills have earlier been identified. For example, Axelsson et.al, 2006 investigated the potential to liberate a steam surplus in an average Scandinavian mill. The hemicelluloses extraction was, however, not considered in that study. Marinova et al., 2009, identified energy efficiency measures to reduce the steam demand of a Canadian kraft mill including a hemicelluloses utilization process; however, the consequences of

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hemicelluloses extraction on the steam balance of different parts of the mill (except for the recovery boiler) were not taken into account. The aim of this paper is, therefore, to investigate the changes in steam balance of the studied mill (Average Scandinavian kraft pulp) when hemicelluloses are partly extracted prior to cooking. Furthermore, the comprehensive heat integration potentials for the mill and the HC utilization process are identified and presented.

2. Scandinavian Hardwood Kraft Pulp Mill

The studied kraft pulp model mill produces 1250 ADt/d bleached market pulp from 2328 ADt/d of hardwood. The resource utilization and type of equipment is typical for an average hardwood Scandinavian mill (FRAM, 2005). Almost all the steam is produced in the recovery boiler (See Table 1). A small amount of bark is burned in the bark boiler for steam production (0.034 DSton/ADt pulp), while the surplus bark is sold (0.205 DSton/ADt pulp). Oil is used only in the lime kiln.

Table 1: Steam production and consumption at the mill

	HP	MP	LP	Flashed steam
Production [MW]				
Recovery boiler	219			
Bark boiler	5			
Black liquor flashed steam				(28)*
	224			**28**
Consumption [MW]				
Woodyard (de-icing wood logs)			2	
Steaming of wood chips			7	(14)
Hi-heat washing zone in digester		10		
Hot and warm water system (HWWS)			8	(14)
Combustion air		(5)	(7)	
Other steam users	44	29	112	
	44	**44**	**136**	**(28)**

3. Hemicelluloses Pre-extraction with Near-Neutral Method

The studied biorefinery is based on the near-neutral extraction process described in details by van Heiningen and co-workers (Mao, 2007 and Mao et.al, 2010). In the near-neutral process wood chips are steamed and exposed into a green liquor (3% on wood as Na_2O) and anthraquinone (0.05% on wood) solution. Approximately 10% of the wood mass, mainly hemicelluloses and also some lignin are extracted. The extracted wood chips are washed and sent to the kraft process. The dilute extract from extraction vessel is concentrated by flashing, hydrolyzed, purified and detoxified (See Figure 1). Finally, the detoxified solution is fermented and the produced ethanol is recovered and

* The numbers in brackets refer to non-net users of live steam.

upgraded. An important assumption is that same fermentation yields for both pentoses and hexoses are considered (Mao, 2007).

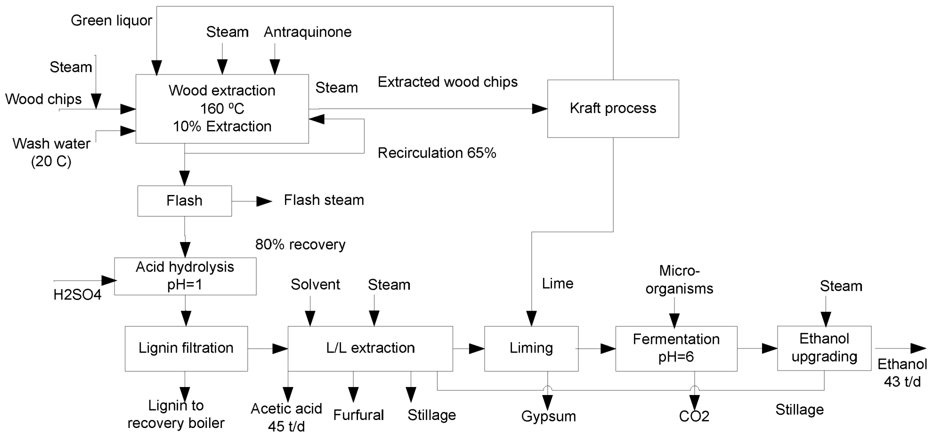

Figure 1: Block diagram of the near neutral process (image adapted from Mao, 2007).

Based on the process described by Mao, 2007, with adaption to the mill studied in this paper, a total of 43 t/d of ethanol and 45 t/d of acetic acid can be produced, while the wood input remains constant.

4. Methodology

In the case of the kraft mill, relevant process data from a computer model is available (FRAM, 2005), whereas for the near-neutral process, mass and energy balances have been generated taking into account available literature data when necessary (Mao, 2007). Thereafter, two different cases, with different level of heat integration have been studied using pinch technology. In the simplest case, the possibility to save steam and liberate excess heat on a stand alone basis (i.e. within each of the processes) is explored. In the second case, the benefits for total integration are studied i.e. heat/steam may also be transferred between the mill and the HC utilization process providing an integrated biorefinery. It should be noted that the impacts of implementation of near-neutral extraction on the Na/S balance of the mill has not been considered in the literature nor in this paper. However, as green liquor is used in the extraction step, the balance may be severely influenced. One may claim that recirculating stillage from acetic acid/furfural separation step (and/or stillage from ethanol distillation) to lean black liquor is an option to tackle the Na/S balance issue. This should, however, be investigated both from energy aspects as well as from a sulfur balance aspect. A more detailed assessment on the Na/S balance of the studied mill is planned to be presented in the coming articles.

5. Results and Discussion

5.1 Base case

The extraction of hemicelluloses alters the steam balance in different ways, resulting in a net steam deficit of 54 MW (See Figure 2):

a) Both the flowrate and organic content of black liquor is decreased, which leads to a reduction in steam production in the recovery boiler (27 MW). Some of this deficit can be compensated by burning the extracted lignin in the recovery boiler (3MW). It should be mentioned that in the literature an assumption of 10% reduction in steam production in recovery boiler was considered for 10 % extraction (Mao, 2007, Marinova et al., 2009). In this paper, however, the steam reduction is calculated based on the changes in heat value of black liquor contents, which results in a larger reduction in steam production (27 MW instead of 22 MW).

b) The decrease in black liquor flow rate would, however, decrease steam demand in the evaporation plant (2 MW).

c) The steam demand at the mill is decreased as the wood chips come already steamed from the extraction vessel (7 MW), and less white liquor needs to be heated in the digester (4 MW), as the incoming wood is partially cooked.

d) The HC utilization process has an own steam demand (44 MW).

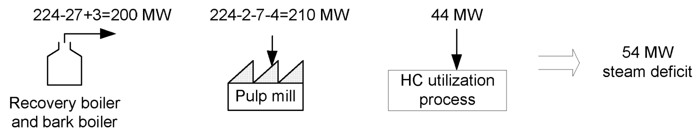

Figure 2: Steam balance when no process integration is carried out.

5.2 Heat integration on a stand alone basis

According to the the Grand Composite Curves (See Figure 3A, 3B) of the mill and the HC utilization process, it is theoretically possible to save 40 MW and 17 MW of live steam, respectively.

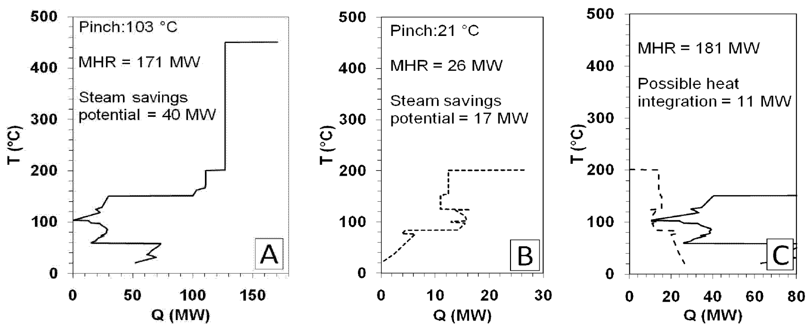

Figure 3: Grand Composite Curve (with individual ΔT_{min}=0.5-8 ºC). 3A, Left: Kraft mill. 3B, Middle: HC utilization process. 3C, Right: foreground-background analysis.

By implementing the measures listed in Table 2, it is possible to decrease the steam consumption of the mill and the HC utilization process. However, the steam produced in the mill is not sufficient and there is a net steam deficit of 23 MW (Figure 4).

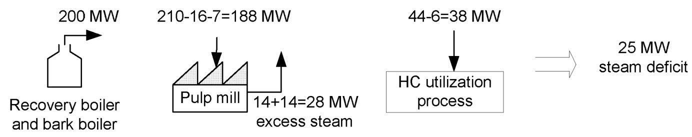

Figure 4: Steam balance when process integration is carried out on a stand alone basis

Table 2: Possible steam saving measures in the mill and HC utilization process

Measure	Steam saving potential [MW]
Mill	
Rebuild the hot and warm water system	8 + 14 (flashed steam)
Use warm water to de-ice wood logs	2
Use flue gases to preheat combustion air	6
	16
HC utilization process	
Preheat the washing water to the extraction vessel (steam savings at the mill + HC utilization process)	7 + 6 + 14 (flashed steam)
	13

5.3 Total heat integration

Total integration makes it possible to achieve higher energy savings as the two black liquor flash steam streams (28 MW) can decrease the use of live steam. According to the background/foreground curve (Figure 3C), 11 MW of the excess heat can be exported from the mill to the HC utilization process and the rest (17 MW) could be used at the mill. In Table 3, potential users of the excess heat are identified.

Table 3: Possible users of excess heat in the mill and HC utilization process

Excess heat user	Steam saving potential [MW]
Steaming of wood chips	10
Digester's washing zone (hi-heat)	10
Distillation of ethanol and by-products	5
TOTAL	**25**

By implementing the measures listed in Table 3, it is possible to decrease the steam demand of the integrated mill and HC utilization process (so called "integrated biorefinery") by 25 MW. Accordingly, the steam produced at the mill is sufficient to make the integrated biorefinery self-sufficient in terms of steam (Figure 5).

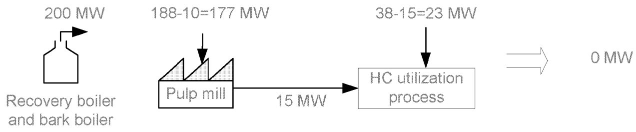

Figure 5: Steam production and consumption at the integrated biorefinery.

6. Conclusions

By implementing hemicelluloses pre-extraction in the studied mill, it is possible to produce ethanol (40 t/d) and kraft pulp (1250 ADt/d). In addition, acetic acid can be produced as a by-product with a considerably good market value. Nevertheless, such implementation alters the energy balance of the mill. Different energy efficiency measures were presented in order to decrease the live steam demand and/or to increase the excess heat in the mill and the HC utilization process. It was shown that when energy savings were achieved in a stand-alone basis, the steam produced at the mill cannot satisfy the total steam demand. However, when total integration is considered, the steam produced at the mill could make the integrated biorefinery to be self-sufficient in terms of steam demand.

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