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Comparison Between a Detailed Pinch Analysis and the 'Heat Load Model for Pulp and Paper' – Case Study for a Swedish Thermo-Mechanical Pulp and Paper Mill

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Pinch analysis has been used for several decades as a tool for making industrial processes more energy efficient by identifying process integration opportunities. Hakala et al. (2008) recognise that pinch analysis is a powerful tool when it comes to improving energy efficiency in mechanical pulp and paper mills, however often very time consuming due to the extensive need for input data. The heat load model for pulp and paper (HLMPP) tool was developed at Aalto University in Finland as a means of providing a flexible tool for a first quick scan of process integration potential. The intention of this study is to evaluate if the model can accurately estimate the data necessary for performing a pinch analysis for a Swedish thermo-mechanical pulp (TMP) and paper mill.
Jönsson et al. (2010) used the HLMPP tool to evaluate the potential for steam savings for four Scandinavian TMP mills. It was found that the minimum steam demands were 2-20 % lower than the current consumptions in the mills. In this study, a detailed pinch analysis was carried out for one of the studied mills described by Jönsson (the mill with the lowest energy savings potential according to the HLMPP screening) to identify strengths and shortcomings of the HLMPP tool.
An initial comparison shows that the pinch temperature and demand for hot and cold utility predicted by the HLMPP tool, as presented by Jönsson, differs from the detailed pinch analysis. However, further investigation showed that the HLMPP results can be aligned to the detailed data with good accuracy if more time and knowledge about the process is put in to the model.

1. Introduction

Pinch analysis has now been used for several decades as a tool for making industrial processes more energy efficient and to identify process integration opportunities. In this work, we present the results as grand composite curves (GCC), which represents the net heat demand, or deficit, in a process at given temperature levels. For a detailed description of the methodology, see for example Smith (2005). Hakala et al. (2008) recognise that pinch analysis is a powerful tool when it comes to improving energy efficiency in mechanical pulp and paper mills, however often very time consuming due to the extensive need for data input (stream data). Therefore, the heat load model for pulp and paper (HLMPP) tool was developed as a means of providing a flexible tool for a first quick scan of possibilities for efficiency measures. Using the tool, it is possible to perform an initial study within only a few days. If the study then indicates promising possibilities for improvements it is recommended to perform a detailed pinch analysis (Hakala et al., 2008). The tool makes use of the simulation software BALAS for heat and mass

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balance calculations, Microsoft Excel for data manipulation and Pro_Pi for pinch analysis. Stream data is generated by the model by specifying certain accessible characteristics for the evaluated mill, for example source of pulp (recycled, kraft or mechanical pulp), temperature levels for available utilities, paper recipe and dry content of material flows at certain positions. Hakala et al. (2008) compared the results from the HLMPP tool with a pinch analysis made for a mill producing pressurized ground wood (PGW) and found the results to be promising. They conclude that the level of accuracy obtained by the tool is sufficient for a first screening.

In another study, by Ruohonen et al. (2009), the model is evaluated for a simulated mill with one thermo-mechanical pulp (TMP) line and one paper machine (PM). Also results from this study shows that the HLMPP tool corresponds quite well to results gained from a detailed pinch analysis. The tool was also used to evaluate possible process modification done for a real mill, to show how these changes would influence the energy efficiency of the plant.

Jönsson et al. (2010) used the HLMPP tool to evaluate the potential for steam savings for four Scandinavian TMP mills. In the present study, a detailed pinch analysis was carried out for one of the mills (mill number 2 in the paper by Jönsson et al. (2010)) to evaluate how well the model predicts the availability of excess heat from the mill and potential for heat pumping. Mill number 2 is the mill with the lowest energy savings potential according to the HLMPP screening.

2. Studied mill

The mill, shown schematically in Figure 1, is an integrated TMP mill consisting of three TMP lines, two de-inked pulp (DIP) lines and three paper machines, with a daily production rate of 1,940 tons of newsprint.

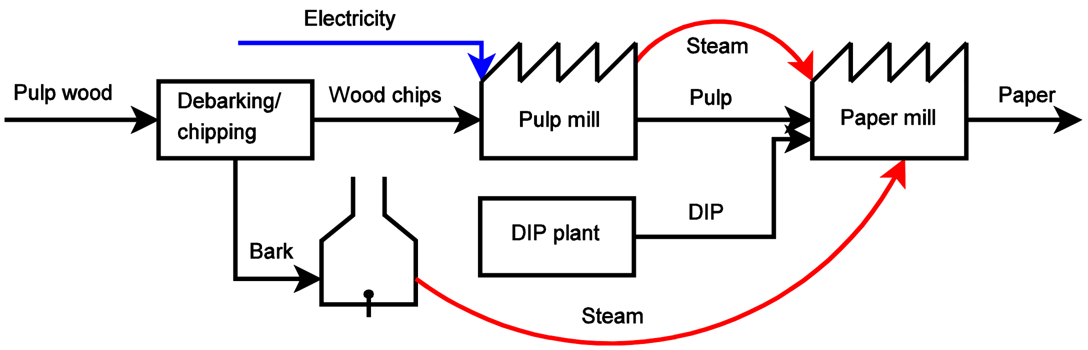

Figure 1: Principle layout of the TMP mill.

Part of the electrical input to the mechanical refiners is converted into steam through friction. Since this TMP-steam can be contaminated by fibres and volatile wood components it needs to be converted into clean steam in reformers before use. Table 1 lists the current major steam users on site and also points out currently used steam which can, or cannot, be replaced with secondary heat taking into account constraints set by the process and process equipment.

Table 1. Steam users.

Process part	TMP	DIP	PM3	Feed water	Atomi-zation	Other 1	Other 2	Sum
Steam that cannot be replaced due to process restrictions [MW]	1		67.8	6.2	3.2			78.2
Steam that can be replaced by secondary heat [MW]		4.7	2.9	3.3		3.9	1.3	16.1
								94.3

Steam users are at wire, press and dryer sections in the paper machines (67.8 MW in total), deaeration steam for condensate and boiler make up water (9.5 MW), and usage of medium pressure (MP) steam for atomization of fuel (3.2 MW) and some smaller consumers of LP steam totalling 5.2 MW. These streams are all presented as heat demands at 137 °C (saturated steam at 3.5 bar) in the following GCCs to show that the steam cannot be replaced by secondary heat.
In his study we have used individual stream contribution to the minimum temperature difference between streams in a heat exchanger according to Table 2 (Axelsson and Berntsson, 2005).

Table 2. Contribution for different stream types to the minimum temperature difference.

Type of stream	Clean water	Dirty water	Steam	Air	Steam with gases
$\Delta T_{min}/2$ [°C]	2.5	3.5	1	8	4

3. Comparison between a detailed pinch analysis and a HLMPP based pinch analysis

The background to this paper is that a detailed pinch analysis was made for one of the mills presented by Jönsson (2010). The results, however, did not match very well with Jönsson's HLMPP results. The model predicted practically no steam savings potential for the mill, compared to 17 % given by the detailed analysis, and the pinch point was estimated by HLMPP to be at 72 °C compared to 53 °C. Also, excess heat below the pinch temperature down to ambient conditions was estimated to be less. A study was therefore carried out to examine the reasons for the discrepancies and to tune the model to better fit reality.

3.1 Adjusted HLMPP

In order to make a fair evaluation of the HLMPP tool, the key process parameters used as input for HLMPP have to be identical to the ones used in the detailed pinch analysis. In the HLMPP input form, the user can choose to specify a limited amount of process characteristics. The characteristics that are of importance for both the detailed pinch analysis and the HLMPP tool are listed in Table 3. While a detailed pinch analysis requires start and target temperature and heat load for all streams, HLMPP needs information about for example daily production rate, furnish mix and dry content of the finished product.

Table 3. Key input data for HLMPP and pinch analysis.

	Unit	
Paper production	[t/day]	1,940
Current LP steam consumption	[MW]	94.3
LP steam from power plant	[MW]	39.7
Total effluent to waste water	[L/s]	168
TMP effluent temperature	[°C]	76.7 (TMP1), 75.4 (TMP2), 74.0 (TMP3)
TMP effluent flow	[L/s]	25.4 (TMP1), 30.2 (TMP2), 24.4 (TMP3), (80 tot)
PM exhaust air moisture content	[g/(kg dry air)]	110 (PM1), 141 (PM2), 160 (PM3)
PM exhaust air temperature	[°C]	71.2 (PM1), 77.0 (PM2), 80.0 (PM3)
PM fresh water temperature	[°C]	10.1
PM effluent	[L/s]	14 (PM1), 26.8 (PM2), 20.1 (PM3)

With input data from Table 3, the HLMPP tool generates stream data resulting in the GCC, shown as the dashed line in Figure 2. Adjustments in input data, compared to the input resulting in the GCC as presented by Jönsson, was done according to the following list.

- One important difference from the HLMPP version presented by Jönsson is the preheating of feed water where it was previously assumed that the water could be warmed up with secondary heat all the way to 130 °C, which is the temperature in the feed water tank, while in fact steam is needed for deaeration. Thus, the heat demand for feed water heating was accounted for twice, since the steam supply necessary to deaerate the feed water was also accounted for manually in the stream data sheet. This is also a matter of user-friendliness, since it is not obvious to the user how the model handles these input.

- Target temperature for inlet air to paper machines is lowered from 100 °C to around 80 °C, depending on paper machine. Final heating from 80 °C to target is in practice accomplished by mixing the inlet air with so called sulzer air from the vacuum system.
- Effluent flows from the paper machines were not included in the original HLMPP data, but do not really affect the conclusions one might draw from the graph due to the low temperature levels (approximately 55 °C).
- Minor adjustments of outlet temperature and moisture content of exhaust air from paper machines.

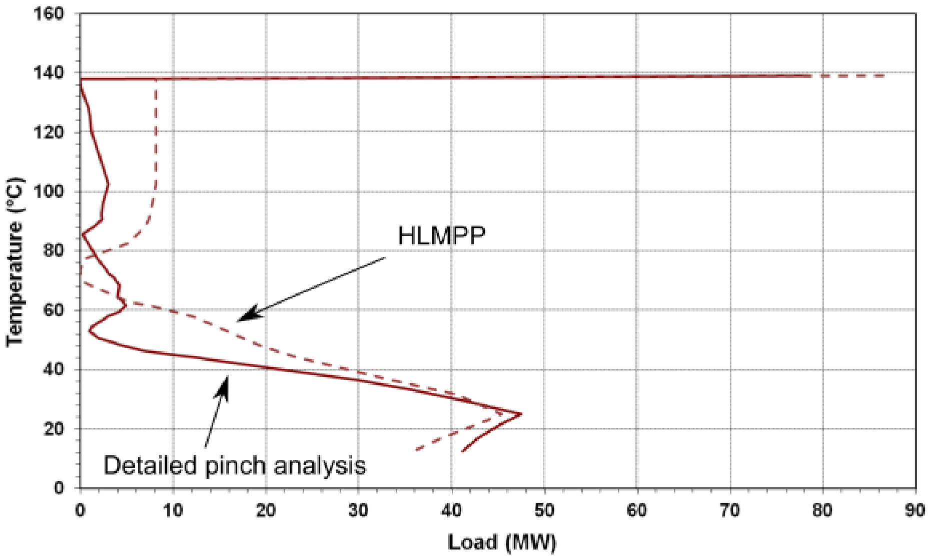

Figure 2: HLMPP GCC as dashed line and detailed pinch GCC as continuous line

Table 4 lists important parameters from the two different methods, HLMPP and detailed pinch analysis, both evaluated for the same paper production. Since this study was done only for one specific mill one should not draw too general conclusions based on these results. However, differences in results could indicate parts of the model that needs further attention and development. This system is especially tricky for the model to estimate since it has practically three pinch points and is therefore sensitive to variations in the streams close to the pinch points.

Table 4: Comparative figures for HLMPP and detailed pinch analysis

	HLMPP	Detailed pinch analysis
Minimum hot utility	86.6 MW	78.2 MW
Savings potential	7.7 MW or 8.2 %	15.9 MW or 17 %
Pinch temperature (lowest)	72 °C	53 °C
Excess heat above 60 °C [a]	6 MW	0 MW

[a] Heat that is possible to use in a new, integrated process, or in a district heating network. Heat below 60 °C is assumed too low for utilization. It has here been accounted for a contribution of 3 °C to the minimum temperature difference.

3.2 Discussion about remaining discrepancies

An analysis was carried out in order to sort out the reasons for the discrepancies between the two methods, the most important parts being the difference in predicted minimum hot utility demand and the deviating pinch temperature. The streams at different locations in the mill were compared individually and the most important ones are being presented in the following list.

Pulp mill

- Chips warming and chips preheating are cold streams in HLMPP, ranging from 9 to approximately 75 °C. In the studied mill, part of this heat duty is satisfied with refiner steam with the combined purpose of heating and steaming (drive off air trapped in the wood).
- Dirty condensate at around 130 °C, from the reformation of TMP steam into clean LP steam, is available according to the detailed stream data extraction. These streams are not included by default in HLMPP, hence the difference between the HLMPP GCC and detailed pinch GCC above the pinch in Figure 2. The stream is generated by HLMPP, however only down to 78 °C, and can be added to the analysis manually. It is not obvious to the HLMPP user if the colder part of the dirty condensate (from 78 °C) from the reformers should be included in the TMP effluent, or if it is automatically accounted for as done for the warmer part. By checking the stream data sheet, generated by HLMPP, one can see that there is no such stream available and it should therefore be added to the effluent in the HLMPP input form, or separately in the stream data sheet.
- Atmospheric steam is generated in the steam reforming process and can be utilized in the process. There is no such stream generated by HLMPP.

DIP plant

- 1.6 MW of heat for dispersing is estimated by HLMPP to increase the temperature of the dispersed DIP mixture from 55 to 75 °C. However, given the real flow of white water collecting the DIP, three times that amount is needed. The difference lowers the pinch point by 0.7 °C.

Paper mill

- HLMPP calculates the heat content in the moist exhaust based on start and target temperature as well as moisture content supplied by the user. Nevertheless, the model underestimates the heat content in the moist exhaust by approximately 3 MW.

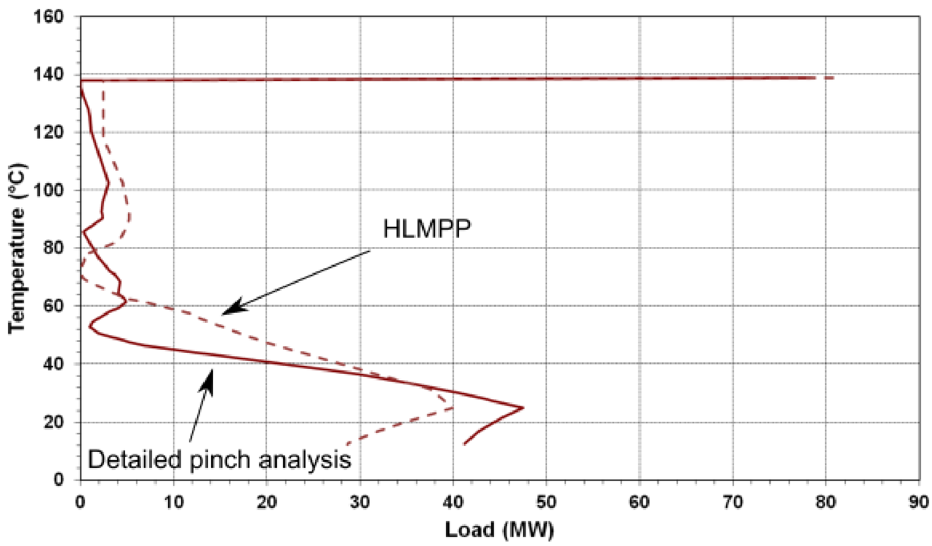

Figure 3: Detailed pinch GCC represented by a continuous line and HLMPP as dashed line, showing the influence of adding the dirty condensate stream in HLMPP (compare with Figure 2)

As stated in the bulleted list above, dirty condensate from TMP steam has a large energy content at high temperatures, after regeneration of clean steam. Figure 3 shows that a pocket, similar to the one presented in the detailed pinch GCC, is at least partly created between 120 °C and 75 °C when this stream is incorporated, making the curves more similar.

A sensitivity test was performed for the detailed pinch analysis to check what influences the pinch point. The streams with the highest energy content around the lower pinch (at 53 °C), and thereby the most influential, are the inlet and outlet air from the paper machines, and the heated fresh water. The flow of moist exhaust air is underestimated by HLMPP, so increasing this flow in the detailed analysis makes no sense. The flow of drying air cannot alone explain the differences, since the streams demand too little energy. A decrease in fresh water supply to the PMs will decrease the heat demand in the region between 10 and 60 °C and will affect the shape of the GCC to become more similar to HLMPP results. It is however hard to say whether the error is in HLMPP or in the detailed stream data set.

4. Discussion and conclusions

The HLMPP method can provide a quick and efficient scan of the potential for energy savings and/or availability of excess heat in a TMP mill, however the results should be used with some amount of caution. The initial comparison between the detailed pinch analysis and the GCC presented by Jönsson et al. (2010) shows that a mill's GCC can take quite different shapes depending on how and when they are compiled. Results from the comparison made after the data input had been synchronized show that there are good reasons to perform a full pinch analysis even though HLMPP only indicates marginal possibilities for improvements. Another source of uncertainty which needs further attention is the estimation of how much live steam is necessary for technical reasons, such as for the drying drums in the paper machines. The software estimates a heat demand of the wire section based on mass and energy balances. However, the true LP steam requirement has to be put in manually afterwards since the prediction is not close enough to the true value. There is also some risk of accounting for certain streams twice, if it is both manually put in as a steam demand and accounted for by HLMPP. All in all, Figure 3 shows that the tool is able to make very good estimations of the mill profile, and the results can be achieved quickly. But, of course, the level of accuracy can only be established once a detailed pinch analysis is in place. Because of the complexity of the tool it should be operated by an expert with good insight in the functionality of program while communication with skilled staff at the mill is equally important. While perhaps lacking precision in estimating flows of a particular mill, the HLMPP tool is convenient if the aim is to evaluate trends and impacts of different process modification on a more general basis. Also the tool could serve well in systems analyses (e.g. Jönsson et al. (2010)) where the energy system of a TMP mill is put in a bigger context, and knowledge about steam consumption and availability of excess heat is of importance.

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