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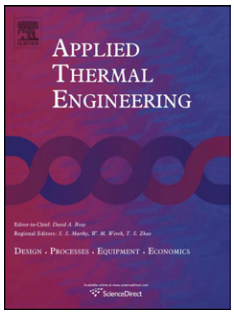

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The potential for steam savings and implementation of different biorefinery concepts in Scandinavian integrated TMP and paper mills

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In this paper the potential for steam savings and excess heat levels is analysed for four Scandinavian thermo-mechanical (TMP) pulp and paper mills, using the Heat Load Model for Pulp and Paper (HLMPP). The results are compared with similar results from previous studies for two other TMP mills. Further, an analysis is made regarding the relationship between the steam consumption and temperature level of excess heat and mill-specific characteristics such as production rate and fresh warm water usage. Based on the results and the analysis, the potential for implementation of different biorefinery concepts is discussed. The results indicate that steam savings of 2-20% can be found in Scandinavian TMP mills. The pinch temperature is rather low, around 20-70°C for most of the studied mills, compared to the pinch temperature usually found at kraft pulp mills (100-140°C). Further, two of the mills show an un-pinched Grand Composite Curve (GCC) where the heat demand curve starts close to 0°C. Thus the potential utilization options for the excess heat are rather limited. The results also show that the level of heated fresh water affects both the steam consumption and the pinch temperature, and thus the potential for efficient integration of different biorefinery processes.

Keywords: *Thermo-mechanical pulp and paper mill, Process integration, Biorefinery, Excess heat*

Abbreviations

CC	Composite Curve	MFC	Machine finished coated
CEPI	Confederation of European Paper Industries	News	Newsprint
DIP	De-inked pulp	PPI	Pulp and paper industry

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GW	Ground wood (pulp)	RCF	Recycled fibre
GCC	Grand Composite Curve	SEC	Specific electricity consumption
HEN	Heat exchanger network	TD	Telephone directory
HLMPP	Heat load model for pulp and paper	TMP	Thermo-mechanical pulp
LWC	Light weight coated		

1. Introduction

The pulp and paper industry (PPI) is currently in a transitional situation, where it is no longer only producing pulp and/or paper but also producing additional products which can increase both the mill profitability and the overall mill energy efficiency – thereby transforming mills into biorefineries. These additional products may be electricity, district heating, wood pellets, dried bark, chemicals, materials (e.g. carbon fibre), biofuels etc. For the conversion of a mill into an energy-efficient biorefinery, it is an advantage if the mill has a surplus of steam and/or heat which can be utilized for thermal integration of the biorefinery processes, or a heating demand at such a temperature level that it can be supplied with heat from the biorefinery processes.

Earlier studies have shown large potentials for generating a steam surplus, and introducing different biorefinery concepts, in the chemical PPI [1-10]. For the mechanical PPI, potentials for steam savings and temperature levels of excess heat have been identified for thermo-mechanical (TMP) model mills [11, 12] and for a few real TMP and ground wood (GW) mills [13-18]. However, for the mechanical PPI, research regarding the potential for introduction of biorefinery concepts based on identified steam savings and excess heat levels has not been performed previously. This is probably due to the fact that, for pulp produced by mechanical pulping processes, usually all wood components (cellulose, hemicelluloses and lignin) are present in the pulp. Conversely, for pulp produced by chemical processes only the cellulose is present in the pulp and thus the lignin and the hemicelluloses can be extracted and used for other purposes. However, this fact does not mean that a mechanical mill cannot be transformed into a biorefinery. It only means that the biorefinery options available for mechanical mills are more limited than for chemical mills.

One way to reduce the process steam demand, and thereby generate a steam surplus which could be utilized in different biorefinery processes, is to thermally integrate the mill processes – process integration. The potential for process integration is most commonly determined by Pinch Analysis [19-21]. However, a full Pinch Analysis requires an extensive amount of data and is therefore relatively time-consuming. To be able to quickly screen the steam-saving potential for a number of mills, the Heat Load Model for Pulp and Paper (HLMPP) can be used [22]. Since the HLMPP simulates the processes to generate part of the stream data, less input data are needed

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compared to a full Pinch Analysis and thus the analysis can be performed using less time. Due to the simulations, the HLMPP results are not as accurate as the results from a full Pinch Analysis. However, the accuracy proven so far is good enough for making pre-studies (aiming at identifying whether a Pinch Analysis is worth performing or not) or for screening potentials for a number of mills [22, 23].

1.1 Aim

The aim of this paper is to analyse the potential for steam savings and identify excess heat levels for four Scandinavian TMP mills by using the HLMPP. The aim is also to compare these results with similar results from previous studies for two other TMP mills in order to see if any general conclusions can be drawn. Furthermore, the paper aims at discussing the potential for thermal integration of different biorefinery concepts in TMP mills. The discussion is based on the steam savings and excess heat identified with the Grand Composite Curves (GCC) generated by the HLMPP.

Finally, the paper will also analyse whether there is any relationship between the specific steam consumption and the temperature levels of excess heat available and mill-specific characteristics in the form of key process parameters (technical age of equipment, TMP share of pulp used, daily paper production and fresh warm water usage).

1.2 Delimitations and system boundaries

The mills included in this paper have different characteristics and have been chosen in order to show the steam-saving potential for different types of TMP-based pulp and paper mills. The reason for choosing mills with TMP lines is that amongst the mechanical pulp and paper processes, TMP is the most promising process to convert to a biorefinery due to the possibility to recover steam from the high-pressure refiners. The absolute majority of the European TMP production is located in Scandinavia (>70%), as is also a majority of the chemical pulp production. This is probably due to the abundance of wood raw material and historically low electricity prices. Thus, the mills included in this study are all Scandinavian. This study assumes a future situation where the fossil fuel prices are high and the availability of biomass is limited. Thus, it is assumed that it is of interest for the mills to keep the imports of fuel to the mill at a constant level or, if possible, to decrease them. A potential steam surplus generated by improved process integration can therefore be used either to reduce the fuel usage, to facilitate introduction of new, more energy-efficient refiners, or for energy-efficient integration of new biorefinery processes.

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2. Method

In this paper four mills have been analysed using the HLMPP in order to identify the levels of potential steam savings and excess heat. The HLMPP, which is further described in Section 2.2, is a process integration tool partly based on Pinch Analysis, briefly described in Section 2.1. For comparison, and for the analysis of the relationship between fresh warm water consumption, steam use and pinch temperature, the results from the HLMPP analyses of these four mills are used together with data from two previous studies.

2.1 Process integration and Pinch Analysis

Process integration is a holistic method used for process design, where one considers the interaction of different process units and aims at optimizing the whole studied system rather than optimizing each process unit separately [20, 21]. In this paper, process integration refers to the concept of thermally integrating the heat sources and heat sinks of a process or a system in order to improve the internal heat exchange and thereby reduce the need for external hot and cold utilities. Pinch Analysis [19, 20] is a well-known and widely used process integration method. The aim of thermal Pinch Analysis is to identify process integration opportunities through increased internal heat exchange and thereby show how the hot and cold utility demands can be reduced. Pinch Analysis can be used both for green field designs and for retrofitting existing processes or plants. A Pinch Analysis for retrofitting existing processes or plants consists of four steps:

1. Data gathering of stream data for the process and data for the utility system.
2. Targeting, where the hot and cold Composite Curves (CCs) and the Grand Composite Curve (GCC) are established. From these curves the theoretical minimum hot and cold utility demand can be determined.
3. Mapping of the layout of the existing Heat Exchanger Network (HEN).
4. Retrofit, where the layout of the existing HEN is improved by removing pinch violations in order to get closer to the targets identified in step 2.

Step 1 has to be performed manually while steps 2-4 can be performed by using some Pinch Analysis tool, e.g. the Excel Add-in ProPi® [24]. The data gathering (Step 1) is usually the most time-consuming part, sometimes constituting up to 75% of the total analysis time. In this paper only the data gathering and the targeting (steps 1-2) are of interest since an HLMPP analysis does not correspond to a full Pinch Analysis as further described in Section 2.2.

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2.2 The HLMPP tool

The modelling tool used for identification of the steam-saving potential, Heat Load Model for Pulp and Paper (HLMPP), is a tool developed for estimating the potential for energy-efficiency improvements through process integration [22]. The HLMPP tool and methodology are based on Pinch Analysis and an overview of the four steps comprising an HLMPP analysis is shown in Fig. 1. As can be seen in the figure, these four steps more or less correspond to the first two steps in a full Pinch Analysis (as described in Section 2.1). The large difference is that the data gathering is not performed in the same way as for a Pinch Analysis. In a full Pinch Analysis, data for all streams which have either a heating or a cooling demand are gathered and the existing heat exchanger network for these streams is mapped. In an HLMPP analysis, only key data for the processes are gathered (see Step 1 in Fig. 1) and the mill processes are then simulated, based on these data together with pre-defined default values for other, less important, parameters using the Balas® simulation software [25] (see Step 2 in Fig. 1). A stream data table is then constructed and given in Excel as an output from the Balas® process simulation (see Step 3 in Fig. 1). Once the stream data table is constructed, the targeting proceeds in the same way as for a full Pinch Analysis (see Step 4 in Fig. 1). The results gained from the HLMPP used in this paper are mainly the Grand Composite Curve (GCC) from which the theoretical steam-saving potential, pinch temperature and amount of excess heat can be determined.

2.2.1 Differences between an HLMPP analysis and a Pinch Analysis

Using the HLMPP tool, the stream data used for construction of the CC and GCC (see steps 3 and 4 in Fig. 1) are given by process simulation and thus do not correspond to the set of real streams at the mill. What are depicted as one stream in HLMPP may actually be two or more streams at the mill. Further, since the HLMPP is simplified and based on a selection of process parameters, the full process layout remains unknown as does the actual location of streams and heat exchangers. Due to the fact that the stream data are obtained from a process simulation and therefore the HEN is not known, steps 3 and 4 in a full Pinch Analysis (Original network design and Retrofit, see Section 2.1) cannot be performed since these steps require good knowledge and data for the actual physical streams and the existing HEN. However, since the HLMPP tool simulates the processes based on both input data from the mills and pre-established default values in the model, considerably less input data are required to get the complete stream data for an HLMPP analysis than a complete Pinch Analysis. This time-saving characteristic, which is the main advantage, makes the HLMPP suitable for screening of saving potentials, as when doing a pre-study or a more aggregated study (such as the study presented in this paper). Yet one should note that since some parts of the processes are simulated based on default values, the stream data are

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not as correct as for a full Pinch Analysis, and thus a more thorough analysis should be done before any investment decisions are made. Thus, an HLMPP analysis cannot be used as a substitute for a full Pinch Analysis but rather as a tool to quickly determine whether a full Pinch Analysis is worth the effort (that is, if large potential savings are identified using the HLMPP) or to get a quick estimation of how the CC and GCC look and thus see the potential for integration of other, new processes in the mill.

2.2.2 Accuracy of the HLMPP

To a large extent, the accuracy of the HLMPP depends on how well the default values set in the model correspond to the real values of the same process parameters in different mills. Such knowledge can only be gained by applying the model to several mills and thereby checking the accuracy of the default values as well as the results given by the model. In the HLMPP model, the mill-specific parameters include the production mix, recipes, water consumption of the mill, specific electricity consumption (SEC) for the refiners, flow rates and temperatures for the filtrate circulations and process temperature, pressure and consistency in the most important parts of the mill process. Other values, such as description of the physical properties of the refiners, heat recovery possibilities from the TMP steam, efficiencies of electrical motors, amount of solids lost in the TMP steam and air leakages, are treated as constant default values for the different mills. Parameters which impact the shape of the GCC, and for which default values are used, are primarily the cooling duties at different parts of the mill, listed in Table 1. The cooling duties have an effect on the overall mill cooling demand and thus the shape of the GCC below the pinch point. Due to this fact, the main uncertainties regarding the accuracy of the GCC generated by the HLMPP is related to the cooling demand and thus the amount and temperature of the excess heat available. The settings of the default values do not come from any individual mill, but can be seen as a combination of typical values within the pulp and paper industry.

In previous studies, the HLMPP tool has given results which correspond quite well to the results obtained by detailed analysis both for pressurized ground wood (PGW) mills and for pulp and paper mills with TMP and DIP lines [22, 23]. Even though further validation, by comparison of HLMPP results and detailed results, is recommended, the accuracy proven so far is satisfactory [22, 23].

3. The studied system: Input data for included mills

For the discussion presented in this paper, data and results for six mills – one model mill and five real mills – are used. An overview of the mills included in the study is given in Table 2. The minimum temperature differences used are presented in Table 3. The data and the HLMPP analysis for mills nos. 1-4 were gathered and performed for the study presented in this paper whereas the data and results for mills 5-6, used for comparison,

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are based on previous studies [12, 18]. All of the mills studied are integrated mechanical mills where the pulp production mainly is TMP. As can be seen in the table, the mills range from rather small, 280 kt/year, to quite large, 780 kt/yr. It can also be seen that the specific electricity consumption (SEC) in the refiners varies depending on the paper quality produced; e.g. the two mills producing supercalendered magazine paper (SC) have a significantly larger SEC in the refiners, compared to the mills producing newsprint (News) and telephone directory paper (TD). Since the steam recovered from the refiners is proportional to the electricity input, the SEC in the refiners impacts the amount of supplementary steam needed to be produced in boilers. Apart from one mill, Mill 6 which is a state-of-the-art model mill producing SC paper, all of the mills studied produce steam in boilers to supplement the steam generated by the TMP heat recovery.

From the table, it can also be noted that the consumption of heated fresh water differs a lot between the studied mills. This is due to the many technical differences that exist between the mills. For example, the quality requirements for the water used in different parts of the process and the equipment used for water treatment result in large differences in fresh water consumption. Also the different paper qualities require different amounts of virgin fibre and cause limitations on the fibre type that can be used. This has an impact on the heat balance of the plant, due to the changes in heat recovery possibilities. In the same way, all other technical and operational differences of the different mills all have their own impact on the steam demands shown in Figure 1. A description of which of the differences are modelled individually for each mill can be found in Section 2.2.2.

4. Results and discussion

The main results are presented in Table 4 and in Figures 2, 3 and 4. The results presented in Table 4 and in Fig. 2 are discussed in the text below, whereas the results presented in Fig. 3 and Fig. 4 are discussed and displayed in Section 4.1. In Table 4 the results from the HLMPP analysis (or Pinch Analysis for Mill 6) in the form of theoretical steam-saving potential and pinch temperature are shown both for the four mills analysed in this paper and for the two mills used for comparison. The corresponding GCC curves for all of the mills are presented in Fig. 2. As can be seen in Table 4, the theoretical potential for steam savings for the four mills studied in this paper ranges between 2 and 20%. These levels of steam savings are comparable to the levels previously identified for TMP mills; see Mills 5-6. However, as can be seen in the table, both the current steam use and the amount of theoretical steam savings identified vary a lot between the different mills. Furthermore, in Fig. 2 it can be seen that, in general, there is excess heat available but it has a rather low temperature (excess heat is defined as the heat available below the pinch temperature, and thus the excess heat available holds <64°C for most of the studied mills). Only one mill has a pinch temperature >80°C and that is a state-of-the-art model mill.

Further, it can be seen that two of the mills, Mill 4 and Mill 5, only have a heating demand and thus their GCCs are un-pinched. For these two mills the heat demand curve starts close to 0°C; this indicates a high water usage and, hence, some of the fresh water, heated to a rather moderate temperature level, will be heated using external hot utility (steam). Finally, from the GCCs, it can also be seen that for Mills 1-3 there is a small temperature span between the heating demand and the cooling demand just around the pinch point. This indicates that implementation of a heat pump could be of interest since heat from below the pinch could be raised to a temperature above the pinch with a small temperature lift, saving additional 2-12 MW of steam for Mills 1-3, corresponding to ~7-8% of the mills' original steam consumption. Such savings only represent a small part of the total steam demand; however, it could still be a profitable investment alternative and should be further investigated.

4.1 Correlation between key process parameters and steam consumption

To be able to draw some general conclusions regarding the steam use and the potential for steam savings, an analysis was done to try to identify any relationship between steam use and the potential for steam savings and other important process parameters. The parameters studied were:

1. Technical age of equipment
2. TMP share of pulp used
3. Daily paper production
4. Fresh warm water usage

The data for Parameter 1, technical age, are based on estimations made by consultants at Pöyry. The technical age of a mill, or specific parts of a mill such as the paper machine, is determined both by when the equipment was bought and by what investments have been made for the equipment since it was first installed. Thus it can be used to e.g. estimate the efficiency or be used for benchmark purposes when comparing different mills with each other. The data for Parameters 2-4 were given amongst the input data specified by each mill.

For Parameters 1-3, no significant correlation was found, either with the current steam consumption or with the theoretical minimum steam consumption. A correlation was found only for the fourth parameter, the fresh warm water usage, as presented in Fig. 3. As can be seen in Fig. 4, the fresh water usage also affects the pinch temperature, or for the two mills with un-pinched GCCs; the start temperature for the heat demand curve. A low fresh warm water usage gives a high pinch temperature and thus a more usable temperature of the excess heat available. These results are in line with similar results from previous studies made on kraft pulp mills showing that a lower use of heated fresh water gives excess heat at higher temperatures and thus a larger potential for

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further process integration [26, 27]. Hence, it can be concluded that water management is important, also for energy efficiency purposes in mechanical pulp and paper mills, and that the energy and water demand at a mill should be analysed together when striving to reach increased energy efficiency. For example, the approach for simultaneous energy and water minimization within the process industry, which has been developed by Savulescu et al. [28, 29], could be used in such an analysis.

Even though no relationship was identified between the TMP share of pulp used and the process steam consumption, it should be noted that the TMP share affects the amount of steam which can be recovered from the refining process and thus affects the ratio between steam recovered from mill processes and supplementary steam produced by boilers. Consequently, even though a mill with a high TMP share does not necessarily have a lower process steam consumption, it most certainly has a lower share of steam produced in boilers compared to a mill with a low TMP share of the pulp used. This is especially true if the mill also produces a paper grade which requires high electricity input to the refiners, such as SC paper.

4.2 Potential for thermal integration of new biorefinery concepts

For a pulp and paper mill, biorefinery concepts can be thermally integrated in three different ways:

1. Use excess heat, or steam, from the mill processes to cover heat demands in the biorefinery processes.
2. Use excess heat, or steam, from the biorefinery processes to cover heat demands in the mill processes.
3. A combination of the two alternatives mentioned above.

Looking at the data and the GCCs in Fig. 2 it can be concluded that since the pinch temperature is so low for all of the mills but one (the model mill), it can be hard to identify biorefinery processes in which the mill excess heat can be utilized. Further, two of the mills are un-pinched and have no cooling demand and thus no excess heat available. However, due to the same fact, most of the mills have a significant heating demand at quite a low temperature (<100°C). This heating demand could be supplied using excess heat from biorefinery processes if the pinch temperature for the biorefinery is higher than the pinch temperature for the mill; e.g. integration with a saw mill could be of interest, since excess heat from saw mills generally holds a temperature of ~75°C (some even as high as 90°) [30-32].

Further, the results presented in Table 3 show that steam savings of 2-20% could be made in the different mills. This is a theoretical potential; however, previous research has shown that for kraft pulp mills it is reasonable to assume that ~70% of the potential is possible to realise through retrofit measures with good economic performance [26, 33-36]. Assuming that the same figures can be applied to the mechanical pulp and paper industry, this would imply that the current steam demand at the studied mills can be reduced by between 1

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% and 15%. Furthermore, as discussed above, the shape of the GCCs indicates that further steam savings can be made in many of the mills by installing a heat pump. The saved steam, no longer needed in the mill processes, can be used to cover heat demand of new biorefinery processes, or else the amount of fuel used for steam production in the boilers can be reduced.

It should be noted that the discussion presented above is based on the GCCs in Fig. 2, representing the different mills *after* retrofits to achieve the steam savings have been made. If no retrofit measures are made, the mills will have higher steam consumption and the GCCs will not look exactly the same. Such curves, showing the existing steam consumption and pinch temperature, have been constructed and are presented in Fig. 5. As can be seen in Fig. 5, for the mills included in this study the pinch temperature for the existing systems is also low, between 18°C and 62°C, and thus the discussion above is valid also if no retrofit measures to achieve a lower steam consumption are made.

4.3 Comments regarding the HLMPP and further work

The HLMPP is partly based on default values and therefore one must be careful when interpreting the results. The default values are set based on experience from previous studies made by the team of researchers which has developed the HLMPP. However, these studies are limited in number and thus further validation, by studies of other mills, is needed in order to check whether these default values are valid for the mechanical pulp and paper industry in general. As mentioned in Section 2.2.2, the main uncertainties regarding the accuracy of the model are related to the mill cooling demand and thus the part of the GCC below the pinch point.

Further, the model creates the stream table automatically from the input data, but there is no automatic check that the stream table is consistent with the actual process. This control is left to the engineer, and therefore the model should be used only by researchers who are experienced in both modelling of mechanical pulp and paper mills and Pinch Analysis. In future work, improving the HLMPP tool, it would be advisable to add a routine to the HLMPP model to check that both sides of every existing heat exchanger (easy to check from the mill personnel) exist also in the model and that the energy balance of the mill is created in a reliable manner. It should also be mentioned that after completing the work presented in this paper, the accuracy of the HLMPP has been further improved by adding a multi-stage heat recovery of the exhaust air of the paper machines (for the work presented in this study the heat recovery was modelled as single stage).

So far, the HLMPP has been validated by comparing the results gained from the HLMPP with results gained from detailed Pinch Analysis for three different mills. However, on receiving the results from the HLMPP analysis presented in this paper, two of the included four mills decided to engage in further work to make a full

Pinch Analysis of their respective mills. Thus, the HLMPP results presented in this paper will, within the coming year, be validated by these full-scale Pinch Analyses and thereby the reliability of the tool can be further evaluated.

Even though the experience of using the HLMPP has been significantly increased by the work presented in this paper and the fact that it has now been applied to four additional mills, the number of TMP mills analysed using the HLMPP or full Pinch Analysis is still limited. If more mills were to be analysed, it is possible that relations and dependences between more parameters than the heated fresh water usage and the process steam demand and mill pinch temperature could have been identified.

Currently, many new biorefinery concepts are being identified as possible to implement within the pulp and paper industry. To be able to fully analyse how these concepts can be thermally integrated with different types of mills (kraft pulp mills, kraft pulp and paper mills, thermo-mechanical pulp and paper mills, etc.) the full thermal characteristics of these processes need to be known. If the GCCs for such processes are known, they can be compared to the mill GCCs and thus an analysis can be made regarding how the most beneficial thermal integration between the mill processes and the biorefinery processes can be implemented.

5. Conclusions

In this paper, the potential for steam savings and the temperature levels for excess heat were analysed for four Scandinavian TMP mills using the HLMPP. The results were compared to similar results from previous studies of two other TMP mills. Further, the relationship between the specific steam consumption and the temperature levels of excess heat to key process parameters were investigated. Finally, the potential for thermal integration of new biorefinery concepts was discussed on the basis of the steam savings and temperature levels of excess heat identified. Summarizing the results, the following conclusions can be drawn:

- For the mills in the study, the theoretical steam-saving potential varies between 2% and 20%.
- Looking at the shape of the GCCs, three of the studied mills show promising potentials for further steam savings of up to 12 MW (equal to ~7-8% of the mills' original steam consumption) by installation of heat pumps.
- For TMP mills, the level of fresh warm water usage affects both the steam consumption and the pinch temperature and thus also the potential for efficient integration of different biorefinery processes.
- The pinch temperature, and thus the temperature of excess heat, is quite low, ranging from 18-72°C for all of the studied mills (both for the existing configuration of the HENs and if maximum energy recovery is achieved), except for the model mill based on best available technology (which shows a pinch temperature of

117°C if maximum energy recovery is achieved). Further, two of the mills are un-pinched and have no cooling demand and thus no excess heat available.

- Due to a low pinch temperature, possible biorefinery applications for TMP mill excess heat are rare, at least if the mill has a high fresh water usage. However, due to the same fact, thermal integration with new biorefinery processes could supply part of the mill's heating demand and thereby further reduce its current steam demand.
- From the levels of steam savings and temperature of excess heat identified, it can be concluded that the mechanical PPI has a potential for thermal integration of different biorefinery concepts. However, the conditions and possibilities for implementing different biorefinery concepts in a TMP mill are different compared to the conditions and possibilities for implementing different biorefinery concepts in a kraft mill. This is due to the fact that, generally, for a TMP mill, contrary to a kraft pulp mill, the steam savings do not lead to any net steam surplus (since the steam recovered from the high-pressure refiners is not enough to fully cover the mill steam demand, either before or after steam savings have been made), the excess heat has a rather low temperature and all of the wood components are present in the pulp produced.

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Fig. 1. Overview of the four steps constituting an HLMPP analysis as performed in this paper.

Fig. 2. Grand Composite Curves for the mills analyzed in this paper.

Fig. 3. Relationship between fresh warm water consumption and steam use.

Fig. 4. Relationship between fresh warm water consumption and pinch temperature/start temperature for heat demand curve.

Fig. 5. GCC for the studied mills before and after potential retrofits.

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Table 1 List of cooling duties at the mill for which default values are used in the HLMPP

Cooling duty	Value used in the HLMPP	Unit
Paper machine cooling duties (incl. condensers, vacuum cooling, gearboxes etc.)	4.5	$kW/t_{paper92}$
Debarking cooling duties	0.4	$kW/BDt_{debarked\ wood}$
TMP cooling duties	6.3	$kW/BDt_{TMP\ to\ PM}$
RCF cooling duties	2.2	$kW/t_{paper92}$

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Table 2 Data for the four mills studied and two previously studied mills for comparison

	Mills analysed with the HLMPP for this paper				Previously studied mills	
	Mill 1	Mill 2	Mill 3	Mill 4	Mill 5	Mill 6
Production capacity paper [kt/yr]	280	780	600	550	697	456
Paper quality	News/ MFC	News	News	SC	TD/news/ LWC	SC
Type of (virgin) pulp production	TMP	TMP	TMP	TMP/GW	TMP	TMP
TMP fibre content [%]	94	64	61	48	53	58
GW fibre content [%]	0	0	0	8	0	0
RCF/DIP content [%]	0	33	31	0	29	0
Bought kraft pulp content [%]	2	0	0	12	14	12
Filler content [%]	4	3	8	32	4	30
Total steam demand [MW]	48	137	105	105	99	65
Steam produced in boilers [%]	29	47	53	42	32	0
Steam surplus/vented [MW]	2[a]	-	-	-	-	21
Refining SEC [kWh/ADt]	2100/2250	1900/2000	1750/2200	2900	1900/2200	3050
Heated fresh water, divided for each PM [$t/t_{paper92}$]	7.0-12.0	3.7-6.0	8.5-11.2	6.5-22.5	7.5-10	4.7

[a]On a yearly average 2MW is vented; however, the venting is very intermittent.

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Table 3 Minimum temperature differences used

Type of stream	ΔTmin/2 [°C]	
	Mills 1-4, 6	Mill 5
Clean Water	2.5	5
Dirty Water	3.5	5
Steam from refiner	2	2
Clean Steam	1	2
Air	8	10
Steam with gases	4	-

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Table 4 Overview of main results in form of steam-saving potentials and GCC curves for the mills analysed in this study and two previously studied mills for comparison

	Mills analysed with the HLMPP for this paper				Previously studied mills	
	Mill 1	Mill 2	Mill 3	Mill 4	Mill 5	Mill 6
Original steam demand [MW]	48	137	105	105	99	65
[kW/$t_{paper92}$]	*66.3*	*53.4*	*62.6*	*77.2*	*55.8*	*49.4*
Theoretical savings potential given by solving pinch violations [MW]	9.7	2.9	5.1	20.7	9	3.4
[kW/$t_{paper92}$]	*13.4*	*1.1*	*3.1*	*15.2*	*4.1*	*2.6*
Hot water (>80°C) available [MW]	0	0	0	0	0	4.0
[kW/$t_{paper92}$]	*0*	*0*	*0*	*0*	*0*	*3.1*
Pinch temperature [°C]	65	72	65	0[a]	0[a]	117

[a]If maximum heat recovery is achieved; these mills have only a heating demand and no cooling demand. This is shown by un-pinched GCCs and thus the temperature is not a pinch temperature but the starting temperature for the heat demand curve.

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Figure(s)

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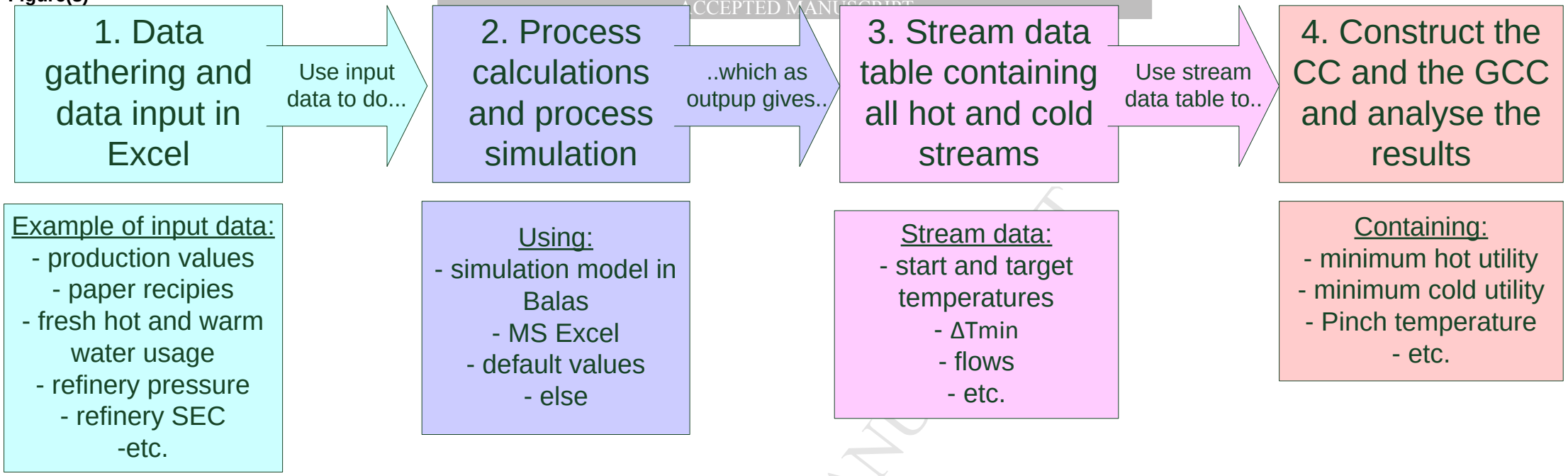

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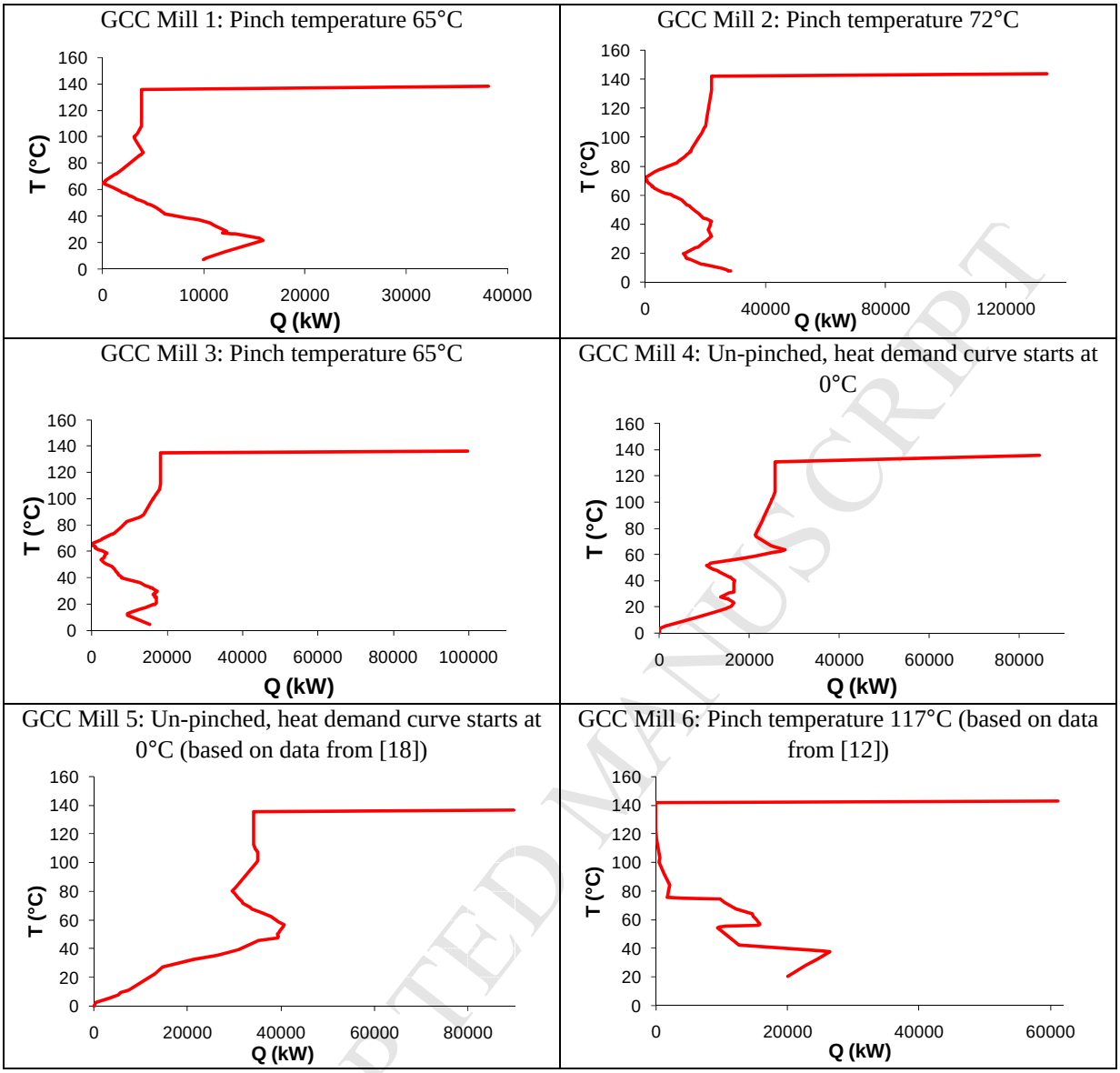

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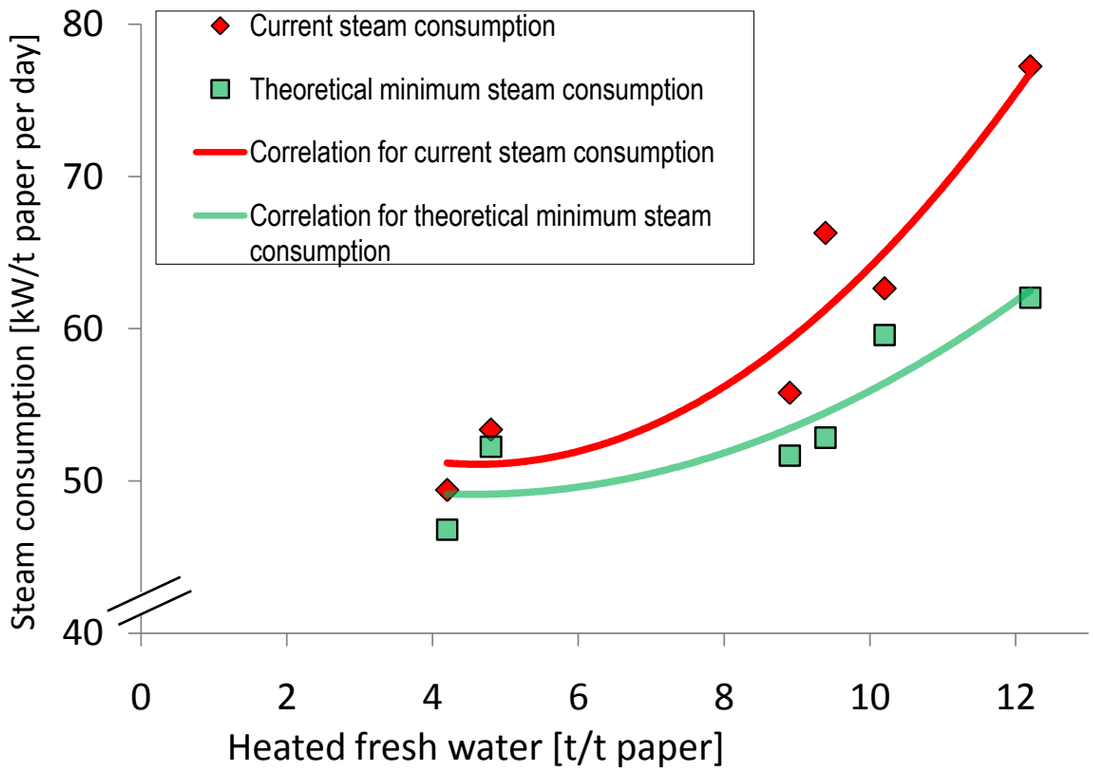

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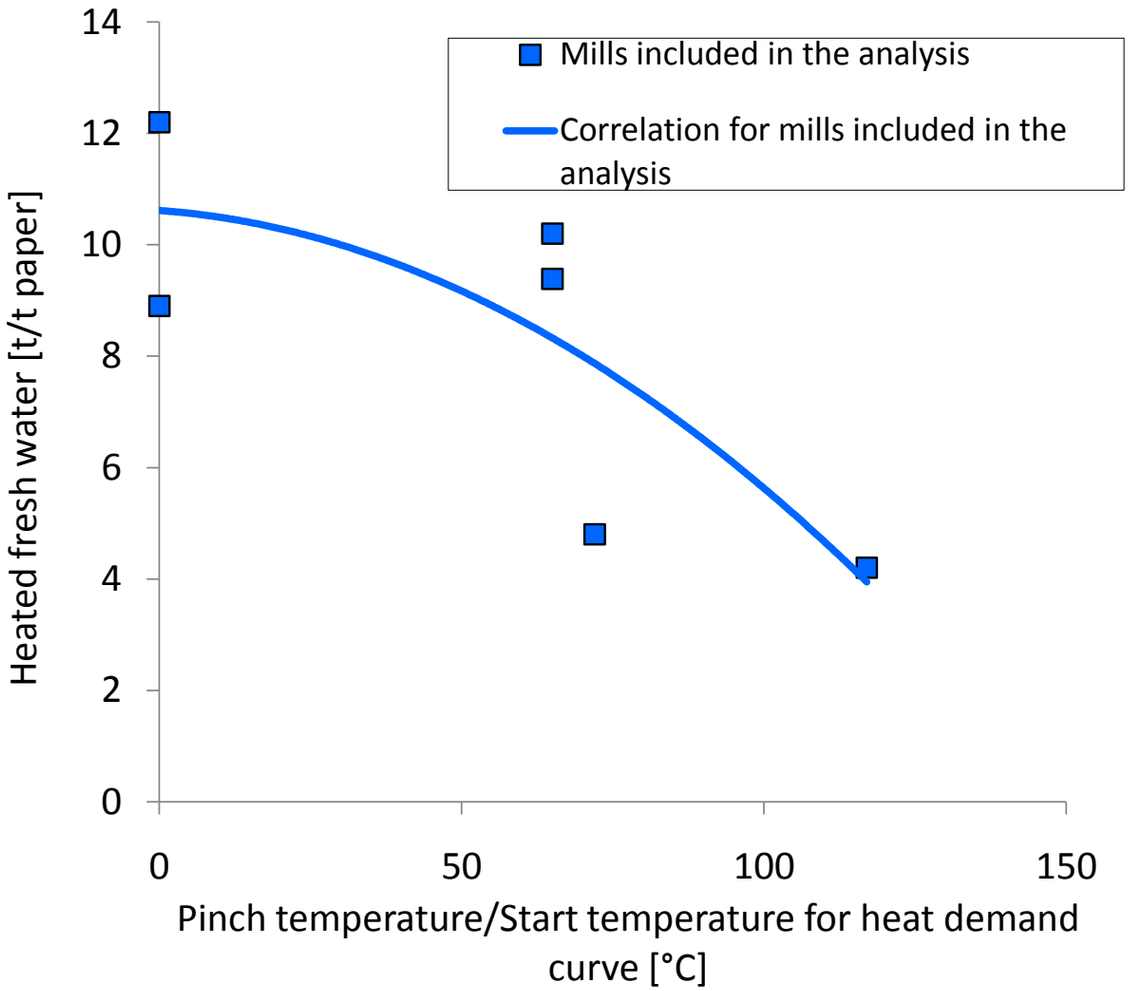

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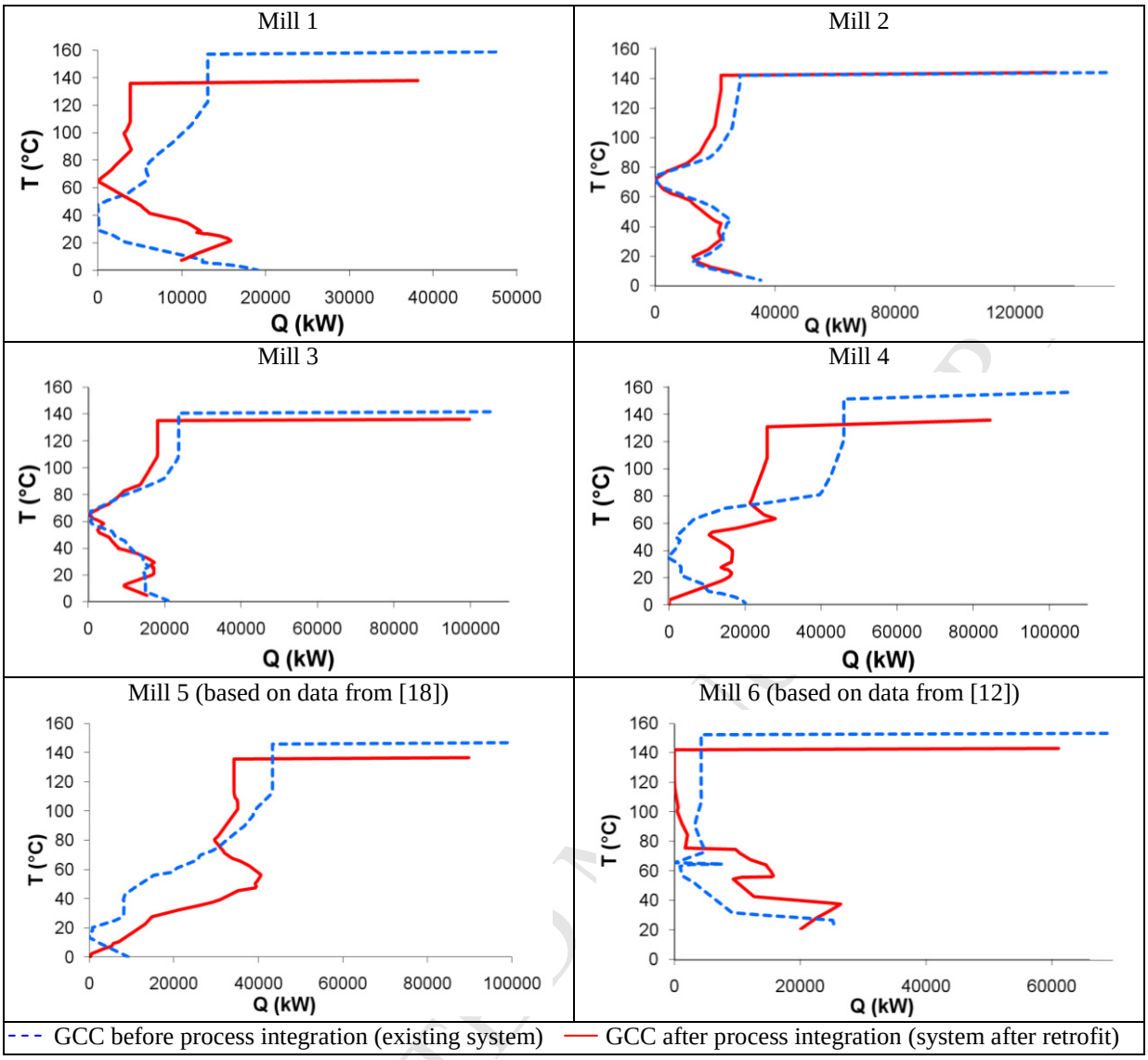
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