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Influence of seasonal variations on energy-saving opportunities in a pulp mill

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ABSTRACT

Significant energy savings can be achieved in the pulp and paper industry through process integration. The aim of this paper was to investigate how much seasonal variations in the process influence the potential for making energy savings. The hot and warm water system in a market pulp mill has been evaluated from an energy point of view, using pinch analysis. Considerable energy-saving potential was found, 40.7 MW, of which 16.5 MW was in the form of steam savings. The steam savings represent 7% of the total steam consumption at the mill. New heat exchanger networks were redesigned using different approaches. The influence of seasonal variations was estimated from the calculated energy savings when monthly averages were used in the new heat exchanger networks. When seasonal variations were taken into account, the energy-saving opportunities fell by 2.5–5.0 MW, depending on heat exchanger network design, compared with a steady-state scenario. Consequently, 88–94% of the theoretical energy savings could be realised. An economic evaluation indicates positive earnings from investment in a new heat exchanger network when seasonal variations were taken into account, even with low prices for the extracted steam and excess heat (5 €/MWh) and with an annuity factor of 0.2.

1. Introduction

Energy efficiency in the pulp and paper industry has come into focus even more amid rising concern about carbon dioxide emissions. Alongside the probable increase in energy prices in the long term [1], it is also more important for industries to reduce their energy costs to remain competitive. This will apply in particular to energy-intensive industries such as the pulp and paper industry, which is the fourth largest industrial energy user in the world [2]. Furthermore, the pulp and paper industry is an industrial sector with potential for making large energy savings [2,3]. A common energy-saving measure is to improve the heat integration with a retrofitted heat exchanger network (HEN). A better utilisation of heat-exchanging opportunities will result in a tighter HEN with a decreased minimum temperature difference (ΔT_{min}), which results in an increased sensitivity to variations in the HEN. In industry, there is a concern that variations could seriously reduce the energy-saving potential compared to the theoretical potential. To deal with the variations, the feeling in industry is that certain margins in the process are required and thus larger heat transfer areas in the heat exchangers than would be necessary if the variables were static. It has yet to be demonstrated clearly how large these margins must be or how great the influence of variations would be on potential energy savings. In this study, it is presented a retrofit of a HEN in a pulp mill and a quantification of the impact of seasonal variations on the identified energy-saving opportunities. A new aspect in this study is the comparison between the energy-saving opportunities when retrofit a HEN in a pulp mill using a steady-state approach and the consequences when taking the seasonal variations into account. If knowledge of consequences of variations could facilitate implementation of energy-saving measures in the pulp and paper industry, this would be a significant contribution to the work on energy conservation in industry.

2. Previous work

Water reduction, process integration and improved energy management are examples of measures proposed to improve energy efficiency in the pulp and paper industry [4–7]. Pinch analysis is a tried and tested method that can be used to identify the opportunities presented by thermal process integration. An account of the methodology in the pulp and paper industry is given by e.g. Lutz [8]. Accordingly, several pinch-based studies have shown that significant energy savings are possible by employing thermal process integration in real mills, such as integrated kraft paper mills [9–11], market kraft pulp mills [8,12] and integrated board mills [13]. For overviews, Fouche and Banerjee [14] and Bruce [6] have reviewed energy-saving opportunities in different studies. According to these studies, a 15–25% reduction in total steam use can be achieved. These studies, however, are performed under

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Nomenclature

a	Annuity factor; see Equation (4)
ADt	Air-dried metric ton (90% solids content)
A_{pipe}	Pipe cross-section area
D_i	Inner diameter of pipe
ΔT_{min}	Minimum temperature difference for the pinch analysis
ECF	Elemental chlorine-free
€	Euro
$flow_{design}$	Process stream flow, used in the heat exchanger network design
GCC	Grand Composite Curve
h_{design}	Heat transfer coefficient, used in the heat exchanger network design
HE	Heat exchanger
HEN	Heat exchanger network
HWWS	Hot and warm water system
i	Interest rate for an investment; see Equation (4)
LP	steam Low-pressure steam at 400 kPa (a)
MWh	Megawatt-hour
n	The economic lifetime of an investment [years]; see Equation (4)
PBP	Simple payback period [years]
Q_{xs}	Excess heat
TCF	Totally chlorine-free

steady-state conditions. In a real case, process variables such as flow and temperature vary continuously and consequently the energy-saving opportunities will also vary.

A large proportion of the energy-saving potential mentioned above is linked to improvements in heat exchange. Several approaches to retrofitting of HEN have been proposed, either using pinch analysis [15–18] or mathematical programming [19]. Processes involving significant changes in operating conditions require the HEN to be flexible, i.e., feasible for different operating modes. To meet this need, Floudas and Grossmann [20] introduced a strategy for optimisation of flexible HENs for multi-period operation. The multi-period approach has been developed further [21–25] and applied in industrial case studies [26]. The multi-period approach could be a fruitful way of handling variations in HEN synthesis and retrofitting although the computation capacity could limit the numbers of periods studied.

Variations can occur in both the short and the long term. Long-term variations, regarded here as variations in a seasonal time scale, can be caused by factors in the surroundings, such as physical properties in wood [27] or outdoor properties, such as temperatures [28], while short-term variations are often caused by disturbances in the process [29]. Little has been done up to now with regard to seasonal variation and its influence on energy-saving potential in the pulp and paper industry. A number of studies have examined seasonal variations in the pulp and paper industry although the primary focus in these studies was on evaluating seasonal variations in wood or chip properties and their correlation with seasonal variations in pulp properties. Studies dealing with seasonal variations are performed mostly in mechanical pulp mills, e.g. [27,28,30], but also in chemical pulp mills [31]. Several studies evaluate the potential for reducing energy use through improved control and thus reduced variability in mechanical pulp processes [31,32], although these studies focus mainly on variations with short time scales.

3. System boundaries

In this study the seasonal time scale was selected to cover long-term variations with frequencies of approximately one month or longer. The differences in the nature of the variations lead to a situation where the short-term variations are mainly superimposed on the seasonal variations. Examples of this are shown in Fig. 1, which shows both the seasonal and short-term variations in the cold water temperature. Furthermore, different measures are required to reduce the variations or to reduce any influence from them in the two cases. Seasonal variations are difficult to manage with improved control, although they could to some extent be managed with changed HEN design. Improved control is more important to avoid large influences of short-term variations. Because of the differences of the variations on the seasonal and short-term time scale, it should be advantageous to study seasonal and short-term variations separately. This is possible since the short-term variations are superimposed on the seasonal variations and have smaller amplitude than the seasonal variations, as shown in Fig. 1. The possible influence from short-term variations is thus not taken into account in this study although it will be examined separately in another paper under development [33].

Variations may occur in the process for very different reasons. For example, possible sources of seasonal variations can be variations in production, fresh water temperature, outside air temperature and temperature or moisture content of incoming wood. However, much of the variation that originates from different parts of the process will end up in the HWWS. Variations in the process will cause variations in the HWWS, and thereby impact on the opportunities for energy savings through improvements in the HEN. This study is therefore limited to the HWWS. Apart from the HWWS, the stripper in the evaporation plant is also included. Heat from the flue gases is not included in the study. District heating is included as a possible user of released excess heat.

4. Aims

One of the aims of this study is to investigate the extent to which energy-savings potential can be realised when taking into account

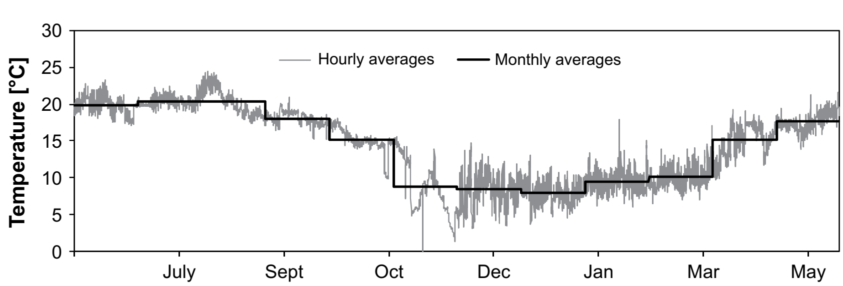

Fig. 1. Cold water temperature. Example on the difference between long-term and short-term variations.