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Methods for Industry to Measure and Improve the Energy Efficiency of Utility Systems

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Industrial utility systems, such as electricity, steam and condensate systems, cooling systems and compressed air, are often considered only as resources to the core production process and may therefore be overlooked by managers and operators in terms of improvement. However, the optimisation of the utility systems may have great importance to energy efficiency and profitability.
Aalto University and VTT Technical Research Centre of Finland have carried out a two-year study where the target has been to test and develop methods for industry to measure and improve the energy efficiency of utility systems. This paper gives a short overview of the most important results of the project.
Possibilities of different process integration and optimisation methods to analyse and improve the energy efficiency of process industry have been tested. A simulated mechanical pulp and paper mill has been used as a test environment. The mill contains one thermo mechanical pulp (TMP) line and one paper machine. The methods included primary energy consumption with different process alternatives, the pinch, advanced pinch and exergy pinch methods and entropy analysis.
In addition, pinch and advanced pinch methods have been used in a case study of an existing mill which produces paper on three paper machines. The mill has three pulp lines; two TMP lines and one DIP line.
In the final phase of the project, two interview studies were carried out. The first study focused on companies in the process industry and the latter on engineering and suppliers of the utility systems. The purpose of these studies was to view drivers for and barriers to energy efficiency in the opinion of the process industry and its most important utility system, technology and service providers. The results are used for focusing future research and development and energy policies.

1. Introduction

The improvement of energy efficiency is seen as one of the most promising measures for reducing global CO_2 emissions and dependence on imported fossil fuels. In Finland, the share of industry is more than half in both primary energy and power consumption

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(VTT, 2007). The share of industry in reduction of primary energy consumption is forcing industrial sector to improve strongly the energy efficiency of the production.

Energy efficiency of the industrial processes can be improved by choosing energy efficient unit processes and equipment, by improved integration between processes and by energy efficient operation of processes. All these need tools to measure and analyze the processes and effect of process changes.

Industrial production processes are enabled by utility systems. Industrial utility systems, such as electricity, steam and condensate systems, cooling systems and compressed air, do not generate profit as such to the industry. This is why the importance of utility systems is often neglected. However, optimisation of the utility systems has great importance for energy efficiency and profitability of the process.

2. Case Studies

2.1 Simulation model

In this project a steady state simulation software application called Balas is used to carry out the process calculations. Information on Balas can be found on the Web at www.balas.vtt.fi. The model itself is an ideal paper plant. For this project, the ideal model was modified to be more like the existing paper mills by adding some additional and thermodynamically incorrect heating and energy uses to it. The modifications were alterations and additions especially to the utility systems in the model. The idea was to create energy inefficient loops in the models in order to evaluate the functioning of energy efficiency methods such as Pinch, Advanced Pinch and entropy-analysis. The model with the thermodynamically incorrect heating and energy uses is called Case 1 and the ideal model is called Case 2.

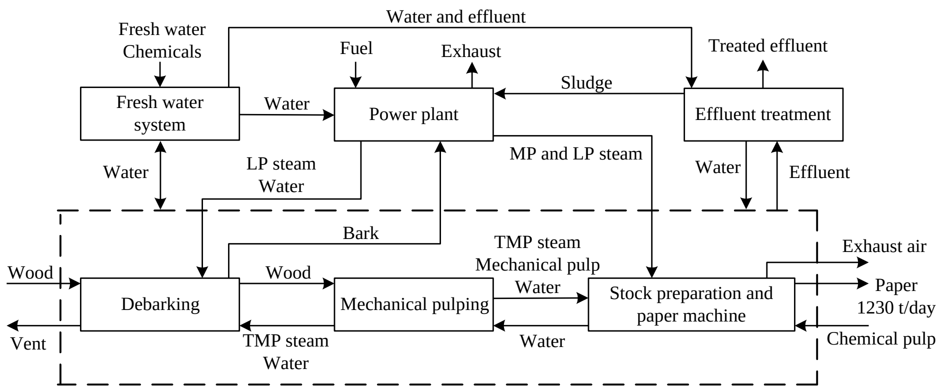

Figure 1. The flows between the sub-processes in the paper machine plant. TMP steam = 300 kPa, low-pressure steam = 500 kPa and middle-pressure steam = 1100 kPa.

The plant consists of a debarking section, TMP plant, paper machine, power plant, fresh water system and effluent treatment. The whole system and the flows between the sub-systems are presented in Figure 1.

The mechanical pulp plant consists of a main refining, reject refining, chip washing, screening, thickening, bleaching and a heat recovery unit. Part of the heat recovered from mechanical pulp plant is used in a debarking and part is used in a paper machine.

The paper machine has two drying sections (pre-dryer and after-dryer). The vacuum system at the wet end has three different executing possibilities. Either it can be done by vacuum pumps or by the turbo blowers. The hot air from the turbo blowers can be used as drying air in the drying section or it can be used for pre-heating the drying air and process waters.

The heat recovered from the drying air is used for pre-heating the hall air, water and drying air. TMP steam and low-pressure steam from the power plant are used for thawing wood, drying paper and heating water, hall air and the wire pit. Middle-pressure steam is used in the paper machine's coating kitchen and supercalander.

Primary energy consumption

The aim of this case was to study how the choice of utility systems affects to the energy usage of papermaking. The effect of different vacuum systems, press sections of the paper machine and drying of the coating were examined. There are many opportunities for implementing these processes and some of the different alternatives were modelled with a simulation program. Primary energy consumption and the usage of the utilities of different process alternatives were investigated. More detailed description of this part is given by (Kontu et al., 2010).

Entropy analysis

Entropy analysis for evaluating the energy efficiency of industrial processes was studied. The aim is to estimate the use of an entropy analysis as a tool for localizing the processes that have highest improving potential when energy efficiency of the whole mill is the goal. Also the influence of the different components and process solutions to the whole mill's entropy generation has been investigated. Processes that use most energy at the paper mill are already well known, but the effects that the different process solutions or components have to the energy efficiency of the whole mill can be difficult to estimate due to the complexity of the processes. In this problem, entropy analysis can be a practical tool.

Results show that the main refining and reject refining processes generates most entropy. This is predictable results based on the high electricity demand of these processes. The entropy generation of the approach and pre-drying processes is also moderately high.

According to the calculations it is possible to discover most of the differences of the two cases. Absolutely the biggest difference of the entropy generation is in the approach system (1 100 kJ/K/t_{paper}) where the wire pit's steam heating is removed. Same effect can be seen at the debarking process where the steam heating is replaced with warm process water. Appreciable changes at the entropy generation also occur at the pre-dryer, after dryer, warm water preparation and hall ventilation processes. This is due to the changes at the heat recovery of the paper machine and the moisture of the paper machine's exhaust air. When heat recovery is less efficient, more steam needs be used for heating processes which increases the entropy generation of those processes.

Results show that the changes at the vacuum system have a slight effect to the paper machine's entropy generation. As expected replacing the vacuum system's vacuum pumps by turbo blowers has the biggest impact to the wet end's entropy generation.

Entropy generation also changes at the warm water preparation, pre-dryer, air ventilation and cooling and heat recovery units. More details about the entropy analysis, calculations and the results can be found from (Federley and Lampinen, 2010).

Pinch based methods

Three pinch based methods; pinch, advanced pinch and combined pinch and exergy analysis were studied. The aim of this case was to investigate which thermodynamic weaknesses these methods can reveal.

In *Pinch analysis* all heating and cooling duties are combined into composite curves. The point of closest approach between the hot and cold composite curves is the pinch temperature. All process heating below the pinch and all process cooling above the pinch can be carried out by heat recovery.

The analysis showed that the amounts of hot and cold utilities used in the simulation model were significantly higher than the minimum amounts required. Some thermodynamic weaknesses and improvement objects could be detected in the model with the help of pinch analysis. The analysis reveals that the hall air should not be heated by TMP steam. Hydraulics, gear boxes and compressed air system should not be cooled with the cooling tower. Instead the heat should be used elsewhere, for example for heating process waters. Heat recovery between TMP and the paper machine should be more effective and the coating kitchen should be heated by TMP steam instead of middle-pressure steam. From the grand composite curve it can be seen that TMP steam (300 kPa) is unnecessarily hot for most of the heating targets. The pinch analysis also shows that steam heating for process waters, the wire pit, debarking and hall air is not necessary.

A method combining pinch and exergy analysis is applied to estimate the exergy losses in the heat exchanger network. Exergy is combined with the pinch analysis by replacing the temperature on the y-axis with the Carnot efficiency. The area between balanced hot and cold composite curves is the exergy loss of the system.

Combining pinch and exergy analysis proved not to be useful when considering the heat exchanger network of a pulp and paper mill. The temperature of the surroundings affects to the entropy loss. There is no systematic method to estimate the real temperature of the surroundings, which causes uncertainty in the results. More information about the combined analysis and the results can be found in (Palo 2009).

The advanced composite curves have been drawn using ΔT_{min} of 55 K. Using this ΔT_{min}, pinch analysis gives targets of 38,127 kW for external heating and 16,310 kW for external cooling, which are the same as utility consumptions given by the simulation model. The pinch temperature for the process with current heat consumption is 41.4 °C.

The results show that the advanced composite curves give a lot more information on the studied system than traditional pinch-based methods. The real temperature levels shown in the curves give guidance to the engineer where to look for improvement potential. The relatively cost-effective part of the improvement potential was identified and the amount given by the analysis can be seen as technically feasible. More information about advanced pinch and the results can be found in (Ruohonen and Ahtila 2009).

Conclusions from the model case study

Pinch analysis has been proven to work well during numerous studies in the past thirty years. The advanced composite curves have been proven in earlier studies to work in chemical pulp and paper industry. Therefore it was expected, that there will be no problem in implementing them in mechanical pulp and paper mill as well. In this study it has been shown that the advanced composite curves give a lot more information on the studied system than traditional pinch-based methods.

When analysis an industrial heat exchanger network, combining pinch with exergy gives no added value when comparing it to traditional pinch analysis. It can be discussed if it might do so in cases with chemical reactions or sub ambient cooling.

Entropy analysis gives theoretically information of the biggest inefficiencies of the process. It remains unclear if this information has some more value than the mere information of the steam and electricity uses.

As a concluding remark, pinch analysis and the advanced composite curves work well. The use of other methods in practice is more complicated. Therefore the advanced composite curves were chosen to be used and tested at an operating mill.

2.2 Pinch and advanced pinch at a mill

The objective of the study is to use the advanced composite curves to analyze an operating TMP mill. The analysis is based on simulations by the HLMPP tool (Heat Load Model for Pulp and Paper). More detailed results of this part can be found from (Ruohonen et al., 2010).

The analysis shows that the advanced composite curves can be used to analyze an operating mill with reasonable extra effort when comparing to pinch analysis. The information given by the curves gives more insight in finding the possible retrofit solutions.

3. Interviews

Two interview studies were carried out in the project. In the first one the target group has been energy intensive industry. In the second one it has been technical consultants and suppliers of equipment and processes. More information about interview studies can be found in (Sivill et al., 2010).

This research produced a significant amount of data on the needs of energy management and energy performance monitoring in the energy-intensive industry. At this point, the adoption of the energy efficiency system (a Finnish management system on energy) has given an important external support to the work of energy efficiency managers in the companies. This work has to be continued with research that could specify further what factors influence the success of energy management and how these factors relate to each other and the interest groups of industry in order to develop relevant energy performance monitoring instruments, energy policies, services and technology. Methods used in this interview study, especially the questionnaire on the success factors of energy efficiency programs, proved to be valuable for further elaboration on these issues.

The interview study among technical consultants and suppliers proved that the interest towards energy efficiency is increasing and that it is already significant factor while choosing equipments and process solutions in many fields of industry. The demands of the customers and new environmental and energy efficiency laws and regulations will force companies to invest to the more efficient and clean technology in a future. This increased importance of energy efficiency creates new business opportunities for the supplier and consults. Especially the service business and offering solutions to customers' problems will be emphasizing in a future. Lot of challenges still exists but the cooperation of supplier, consult and customer is the key thing for achieving an overall energy efficient process solutions.

4. Discussion

Some general conclusions can be drawn from the results of the project:

- Pinch and advanced composite curves are practical tools for mills' energy analysis.
- The methods are not widely used or even well known in engineering companies.
- Optimisation of unit processes is not adequate, but the energy efficiency has to be controlled on mill or integrate level.
- In general, only the amounts of electricity, steam and water are measured. Only limited information about other utilities is available.
- Process and equipment suppliers are willing to find possibilities to exploit energy efficiency in their business operations.
- Performance measurement approach is missing: Management is following the development of the energy efficiency, but the information is missing from the operators.
- Investments may not be necessary: the optimisation of the existing systems leads to significant improvements.

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