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The effect of choice of utility systems on primary energy consumption – Case: press and drying sections of a paper machine

Kaisa Kontu*, Pekka Ruohonen, Ilkka Hippinen, Pekka Ahtila
Aalto University School of Science and Technology, Department of Energy Technology, Industrial Energy Engineering, P.O.Box 4400, FIN-02015 TKK, Finland
kaisa.kontu@tkk.fi

The target of this paper is to study how the choice of the utility systems affects the energy usage of paper making. The study focuses on a simulated mechanical pulp and paper mill. The investigation is made to the vacuum system, press section and drying of the coating in the paper machine. Different technologies based on annular water pumps (liquid ring pump) and turbo blowers are studied for the vacuum system. The influences on energy consumption of the steam box and shoe press were studied for the press section. The alternatives for drying of the coated paper are electric and gas infrared dryers followed by a second cylinder drying section. Case alternatives have different steam and electricity consumption which is taken into account by calculating the change of primary energy consumption. Also the effects on CO_2-emissions are estimated. Additionally, pinch analysis is used for investigation for vacuum system alternatives.

1. Introduction

Paper making is an energy intensive process consuming heat approximately 3 – 6 GJ/t and electricity 450 – 1100 kWh/t. (European IPPC Bureau, 2001). Optimization of the utility systems, such as electricity, steam, and cooling system and compressed air, have great importance to the energy efficiency and profitability of the process.

In a paper machine, vacuum system, which is very energy consuming accounting approximately 17 % of the total electrical energy used on a paper machine, is used for water removal from the wet web and to help in runnability of the web (Räisänen 2000). Vacuum system and different ways of accomplishing it has been investigated in earlier studies but mainly in the sense of optimizing the water recycling.

A 1 % absolute increase in dryness of the web going into the dryer section reduces its steam consumption by 4 to 5 % (McIvor et al., 1999). In this study the influences on energy consumption of the steam box and shoe press were studied for the press section considering the energy consumption of the whole mill.

1.1 The mill

The mill used as an example in this case study has one TMP line, one paper machine, a power plant, and debarking and auxiliary systems. The mill has been modelled with

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Balas simulation software (VTT 2010). More detailed description of the used model and the mill is represented in previous study (Ruohonen et al., 2009,). The same mill is also used as an example in entropy analyse study (Federley et al., 2010).

1.2 Description of the case studies

The investigation of potential improvement of energy efficiency is made for the vacuum system (Cases B and C) and the press section (Cases D and E) of the paper machine as well as drying of the coating (Case F). In the energy efficiency study, different case alternatives are compared with Case A. The case alternatives are briefly described next.

A The vacuum system of the paper machine is accomplished with three annular water pumps which need cooling water 60 kg/s (5 °C). The excess air (17 °C) from the pumps can not be reused. In the press section there is a nip press used and the dryness of the web is 48 % (45 °C) after the press section. Between the predrying and after drying there is section for drying of the coating, which is accomplished with using electric infrared dryer. The power needed for electric infrared dryer is 1500 kW (approx. 29 kWh/t) and the efficiency is 26 %.

B Vacuum system is accomplished with turbo blowers. The excess air from the blowers (128 °C) is used for heating up the process water and air before predrying. Turbo blowers need less electricity than annular water pumps.

C Vacuum system is accomplished with turbo blowers. The air needed for the turbo blowers is cooled down (20°C) before it goes to the blowers which make it possible to use the air as such for the drying air for pre-drying section.

D The steam box is used and the temperature of the web rises 10 °C between the first and the second nip. In this case the dryness of the web after the press section is 49 %. The steam box needs LP-steam (1.5 kg/s).

E The shoe press is used and the dryness of the web after the press section is 53 %. The shoe press consumes more electricity than the nip press.

F The drying of the coating is accomplished with dryer where the heat source is gas. When the drying of the coating is accomplished with gas infra dryer, which efficiency is 40 %, the energy needed is 975 kW (approx. 19 kWh/t).

2. Methodology

Different case alternatives have different steam and electricity consumptions. These are taken into account by calculating the change of the primary energy consumption. The power plant produces both electricity and steam for the mill (CHP-plant). Steam is produced in two pressure levels: MP-steam is 11 bar(a) and LP-steam is 5 bar(a). For the process the LP-steam is reduced for 3 bar(a). LP-steam is available from the TMP-process and rest of the needed LP-steam is produced in the power plant. The power plant produces a part from the needed electricity in the mill. The peak load of the electricity is purchased from the grid.

The energy consumption in winter and summer conditions is considered separately. In winter the temperature of water is 5 °C and air 10 °C. In summer, the corresponding temperatures are 10 °C and 20 °C. This makes it possible to compare different energy flows between each other. In addition, the effects on CO_2-emissions were estimated. The power plant in the mill uses bark and sludge as a base fuel which are received from the mill. Biomass is classified as CO_2-neutral fuel and its emission rate is 0 t_{CO2}/TJ. The

fuel alternatives as a marginal fuel for power plant and their emission rates are coal (108 kg_{CO2}/GJ), peat (106 kg_{CO2}/GJ) and natural gas (55 kg_{CO2}/GJ) (Statistics Finland 2010). The emission rate for electricity bought from the grid is 200 kg_{CO2}/MWh.
Pinch-analysis is used for comparing different alternatives of vacuum system. Pinch-analysis (Linnhoff et al., 1982) is well-known and widely used process integration method. The idea is to convert information on all the heating and cooling needs of the process into targets for hot and cold utility consumption.

3. Results and Discussion

3.1 The alternatives for the vacuum system

The results in the Table 1, where the energy use, fuel input and CO_2-emissions of the whole mill is considered, show that the use of process steam is reduced when turbo blowers are used to accomplish vacuum system (Cases B and C) when comparing to case with annular water pumps (Case A). The differences between winter and summer conditions occur from the difference of the process water temperatures and the need of heating process water. Also the need for cooling water is reduced when turbo blowers are used. In the case alternatives B and C, the fuel input is reduced 1.1 – 2.3 %, depending on winter or summer conditions. This reduces also the CO_2-emissions. In this table, influences on emissions with different fuel alternatives, in terms of electricity use and use of fuel are taken into account. Turbo blowers use less electricity as such when comparing to the annular water pumps. The use of electricity is also reduced because when using turbo blowers, the auxiliary consumption of the mill is reduced.

3.2 Results of Pinch-analysis

The Pinch-analysis has been carried out for vacuum system alternatives using 10 K as ΔT_{min}. The results are shown in figures 1 – 3 for cases A, B and C. The results show that the minimum hot utility demand is smaller in the Case A (annular water pump) in comparison to the Cases B and C (turbo blowers). Minimum cold utility demand is higher in the Case A. The differences of utility demands between Cases B and C are minor in both, winter and summer conditions

Table 1: The use of process steam and electricity, fuel input, and CO_2 – emissions in the Cases B and C in comparison with Case A

		Case B		Case C	
		Winter	Summer	Winter	Summer
Process steam	%	-1.3	-1.6	-1.0	-1.5
Electricity	kWh/t	-53.2	-53.2	-53.2	-53.2
Fuel input	%	-1.6	-2.3	-1.1	-2.2
CO_2-emissions					
- Coal	t_{CO2}/a	-2944		-2702	
- Peat	t_{CO2}/a	-2929		-2691	
- Natural gas	t_{CO2}/a	-2543		-2420	

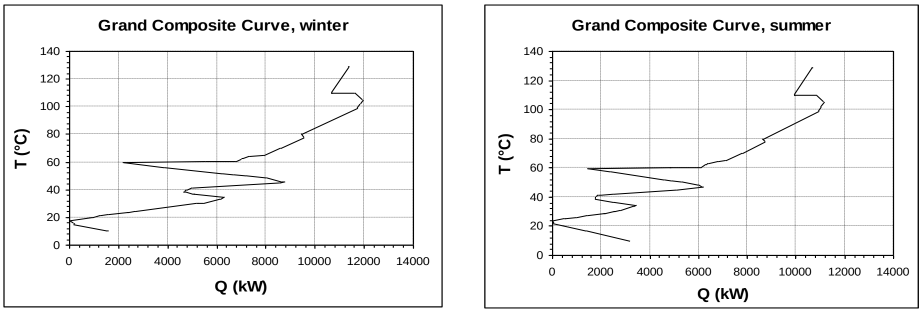

Figure 1: Grand Composite Curve, Case A, winter and summer conditions

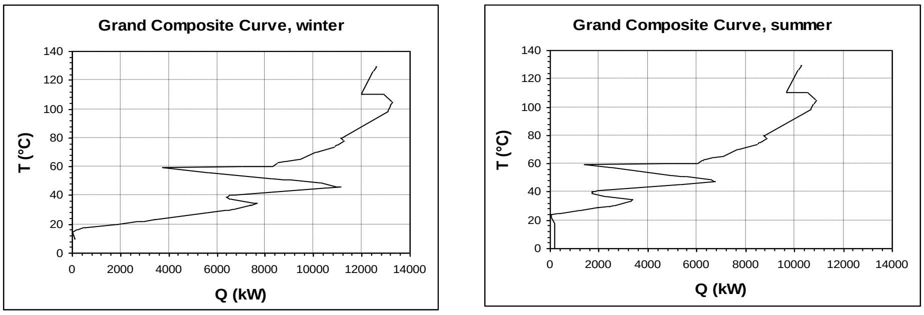

Figure :2: Grand Composite Curve, Case B, winter and summer conditions

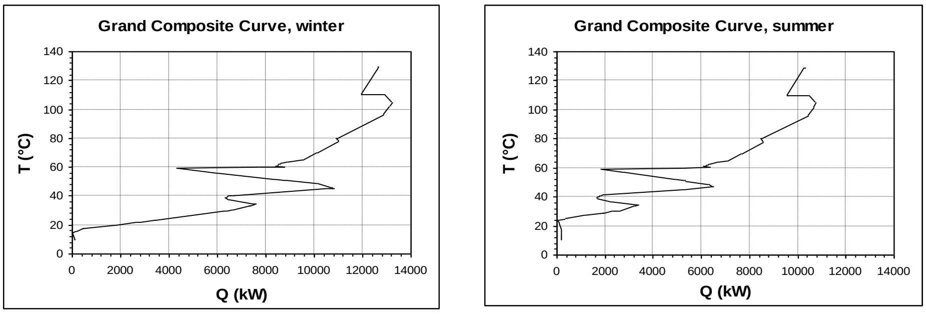

Figure 3: Grand Composite Curve, Case C, winter and summer conditions

The effects of heat demand in different cases with different ΔT_{min} are represented in figure 4. ΔT_{min} had values from 0 K to 20 K. If the heat exchanger network for the mill is designed with small ΔT_{min} then the use of annular water pumps in the vacuum system is advisable. Here it is assumed that the water from the pumps can be reused as a heating demand. If the ΔT_{min} is big then it is sensible to use the turbo blowers and in that way save heating demand. The change of ΔT_{min} is 15 K in winter conditions and 6 K in summer conditions. The smaller the ΔT_{min} is, the higher the investment costs are. This is one reason why turbo blowers should be used. Other reason for this is that when using the turbo blowers, the heat recovery is easier to accomplish. Because the choice for reasonable ΔT_{min} depends on the season of the year, the flexibility of heating network should be considered. With alternative heating networks with different ΔT_{min} for winter and summer conditions would achieve the best energy efficient system.

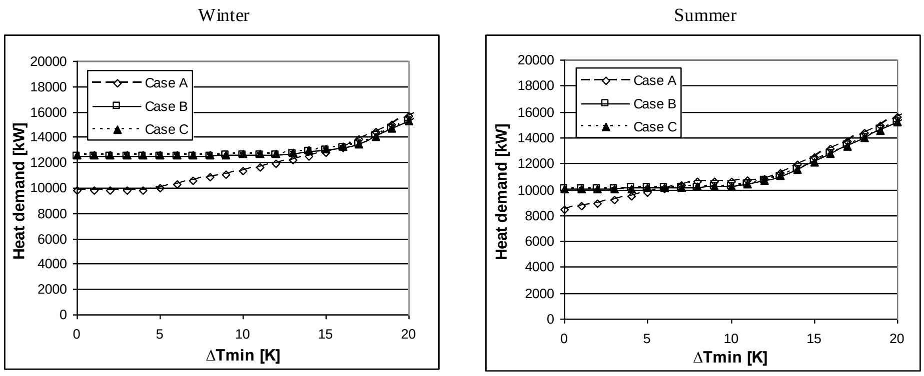

Figure 4. Demand curves, winter and summer conditions.

3.3 Alternatives for press section and the drying of the coating

In this part the effects of energy use when adding the steam box to the press section (Case D) and the use of shoe press (Case E) are studied. The results in the Table 2 show that in Case D, the use of process steam is increased. The steam box needs LP-steam 1.5 kg/s, which is more than the amount of steam, which is saved in the predrying section. The consumption of electricity does not change. Because the fuel input increases in Case D also the CO_2-emissions increases. The results of the Case E shows that adding the shoe press in the press section decreases the use of process steam in the mill. Even though the electricity is used more in this case the operating costs are still lower in the energy section. Also CO_2-emissions decreases. In this table, influences on emissions, in terms of electricity use and use of fuel are taken into account.

When the electric infrared dryer for drying the coating is used, the energy needed per produced paper tonne decreases. This decreases the CO_2-emissions by 834 t_{CO2}/a and also the operating costs are decreased. This study does not take into consideration the possibilities of heat recovery, which would increase the efficiency in Case F.

Table 2: The use of process steam and electricity, fuel input, and CO_2-emissions in the Cases D and E in comparison with Case A

		Case D		Case E	
		Winter	Summer	Winter	Summer
Process steam	%	2.9	3.9	-16.4	-19.7
Fuel input	%	6.2	6.7	-23.7	-20.6
Electricity	kWh/t	0	0	11.7	11.7
CO_2-emissions					
- Coal	t_{CO2}/a	3250		-12008	
- Peat	t_{CO2}/a	3189		-11777	
- Natural gas	t_{CO2}/a	1655		-5885	

4. Conclusions

The effects of the different utility system options were studied on the mill level. The analysis shows the effects of the choice of the utility systems on steam consumption. The different options have different electricity consumptions as well. These were taken into account by calculating the change of primary energy consumption. In addition, the effects on CO_2-emissions were estimated. Pinch analysis was used for comparing steam consumption of different vacuum system alternatives. The results show that these methods can be used to estimate the effect of the different technical solutions in one section of an integrated mill on differences in primary energy consumption and emissions. The same kind of investigation is also applicable in monitoring other utilities, such as compressed air, and other industrial processes.

The example where the use of steam box was investigated illustrated the importance of correct consideration of balance boundaries for the energy consumption. By adding steam box to the press section reduced the energy required for the drying section, but for the whole process it was increased. Also the investigation for the vacuum system with pinch analysis proved that.

The pinch analysis gives a lot of information on the studied system, which could be seen from the investigation made for the vacuum system. It gives not only the heating demands for the system but also other improvement potential for the system.

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