Influence of some Parameters on Heat Transfer during Calendering: Case of a Wood Free Coated Paper

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ABSTRACT

During supercalendering or soft calendering, the process consists of applying extreme pressure on paper under a certain temperature gradient. For a fundamental understanding of what happens during calendering, it is necessary to understand first how heat is transferred from the rolls to the paper web. This requires fundamental work on heat transfer and practical trials to validate theory. The purpose of this work is to furnish certain results validating theory and to observe the effects of certain parameters of the calender (temperature of the heated rolls, dwell time and pressure) and of certain paper properties (coated or not and moisture) on heat transfer in a nip.

INTRODUCTION

Developments of new calendering concepts and new equipment have been very important during the last two decades. Whatever the kind of calender, the process consists of an elastic-plastic deformation of the paper web in one or several roll nips. The simultaneous supply of mechanical energy and of thermal energy modifies the structure and the surface of paper. For each paper grade, papermakers have to find the best balance between mechanical and thermal energy, which requires a great number of trials (1). Many works have tried to establish relationships between paper properties and calendering parameters (2-7), some are oriented towards a fundamental understanding of paper deformation in the calender nip (8-12). But no one has defined a paper rheological behaviour for predicting paper deformation after calendering with respect to paper properties before the nip and to calender parameters. The main difficulties in acquiring this information are: the lack of knowledge of the real geometry of the nip, the lack of knowledge of the pressure distribution in the nip, the lack of knowledge of paper thermal properties (and their variations with moisture, temperature, under compression) and the way temperature interacts with pressure. Indeed, the rheological behaviour of materials is generally temperature dependent. As there is a temperature distribution in the thickness direction of the paper in the nip (13), it seems obvious that it is not possible to establish a general law linking paper deformation to paper properties and calendering parameters. So, it is necessary to consider local temperature variations and rheological properties of paper in the nip. The first step in this process is mastering heat transfer in the nip.

Works dealing with modeling the heat transfer in the nip (14-16), already exist. The purpose of this study is to look for the effects of pressure, dwell time, heated roll temperature, nature (i.e. coated or not) and of paper moisture on heat transfer during a single nip calendering. The results presented here serve as a basis for verifying theoretical heat transfer models, and as a basis for rheological analysis of paper behaviour during calendering.

EXPERIMENTAL

Manufacture of Coated Papers

A 60 g/m^2 wood free substrate was coated with a standard offset lithography coating colour in a pilot coater (CTP's pilot coater, Grenoble, France). Two batches of this substrate were used one with moisture at 4.5% and another with moisture at 6.5%. Both sides of the substrate were coated with an applicator roll and a stiff blade at 1200 m/min.

The coating colour formulation was:

60 parts of clay

40 parts of calcium carbonate

12 parts of styrene- butadiene lattice

0.5 parts of CMC

The coating colour dry content was adjusted at 60%.

Table-1 Paper water content

Paper	Basis weight (g/m²)	Moisture (%)	Water content (g/m²)
Uncoated	60	4.5	2.8
Coated	81	3.5	2.8
Uncoated	60	6.5	3.9
Coated	81	4.8	3.9

The coat weight was 10.5 g/m² per side. The coated materials were dried to two final moisture contents with target values of 3.5% and 4.8%. These target values were chosen in order to obtain coated papers containing the same amount of water per surface unit as the uncoated papers. The calendering conditions are given in Table 1.

So, after manufacturing, we had at our disposal four types of papers: two uncoated papers (one substrate at two levels of moisture) and two coated papers (having the same fibrous phase as the uncoated papers and two levels of moisture as well).

Calendering trials

Calendering trials were performed on a pilot supercalender in one nip. The paper run in the calender is shown in Fig. 1. The nip is made of a heated steel roll and a polymeric soft roll. We were looking for the effects of temperature of the heated rolls, dwell time and pressure on heat transfer in a nip.

The Calendering conditions are given in Table 2.

Testing

During the pilot calendering trials, we measured, for each calendering condition, the temperature of the paper web before and after the nip (which we have called "paper ingoing nip temperature" and "paper outgoing nip temperature"). The measurements were taken with a pyrometer at a distance of about 35 cm from the nip. The ingoing nip temperature and the outgoing nip temperature were not measured on the same side of the paper web (Fig. 1), but considering calender speeds for all the trials, the residence time of the paper in the air draw, before and after the nip, was long enough to ensure that temperature was nearly constant in the thickness direction of the paper (15, 16).

RESULTS AND DISCUSSION

First, we observe web temperature entering the nip (Table 3). The results in Table 3 indicate that the level of temperature of the paper web entering the nip depends on the temperature of the heated roll. That is quite normal since the temperatures of all the heated rolls of the supercalender were monitored by the trial target temperature value. So, before entering the nip, the paper

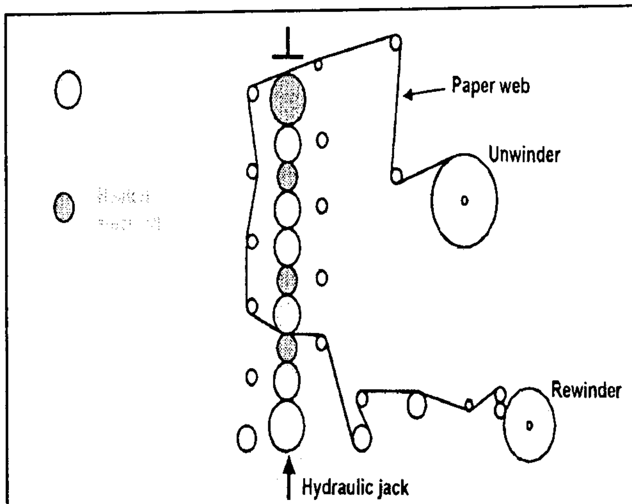

Fig. 1 Diagram of the pilot calender during the calendering trials.

Table-2 Calendering parameters for the pilot scale study.

Temperature	Linear load in the nip (kN/m)	Speed (m/min)	Average pressure (MPa)	Dwell time (ms)
	200	770	38.4	
	250	880	43.5	0.40
50°C, 80°C and 110°C	310	970	48.0	
	200	515	38.4	
(Temperature of the	250	585	43.5	0.60
internal fluid of the rolls)	310	645	48.0	
	200	390	38.4	
	250	440	43.5	0.80
	310	485	48.0	

web passed through a heated atmosphere and near radiating rolls. The results in Table 3 also show that the moisture level does not seem to have any influence on the web temperature before the nip whether the paper is coated or not. Furthermore, coated paper has an ingoing nip average temperature only slightly different from that of uncoated paper. Thus, it is possible to compare the relative effects of moisture, pressure, dwell time and temperature of the heated rolls, on the heating of the web in the nip for uncoated and for coated papers.

Fig. 2 represents the effect of moisture and coating on paper average temperature. The temperature (before and after the nip) of the paper containing more water is compared to the temperature (before and after the nip) of the paper containing the less water, for all the runs.

Fig. 2 demonstrates that the moisture level (in the considered range) does not seem to have an effect on the web heating in a nip as all the data gathered are grouped at the first bisector line of the figure. Advancing with conclusions, it becomes interesting to compare the effects

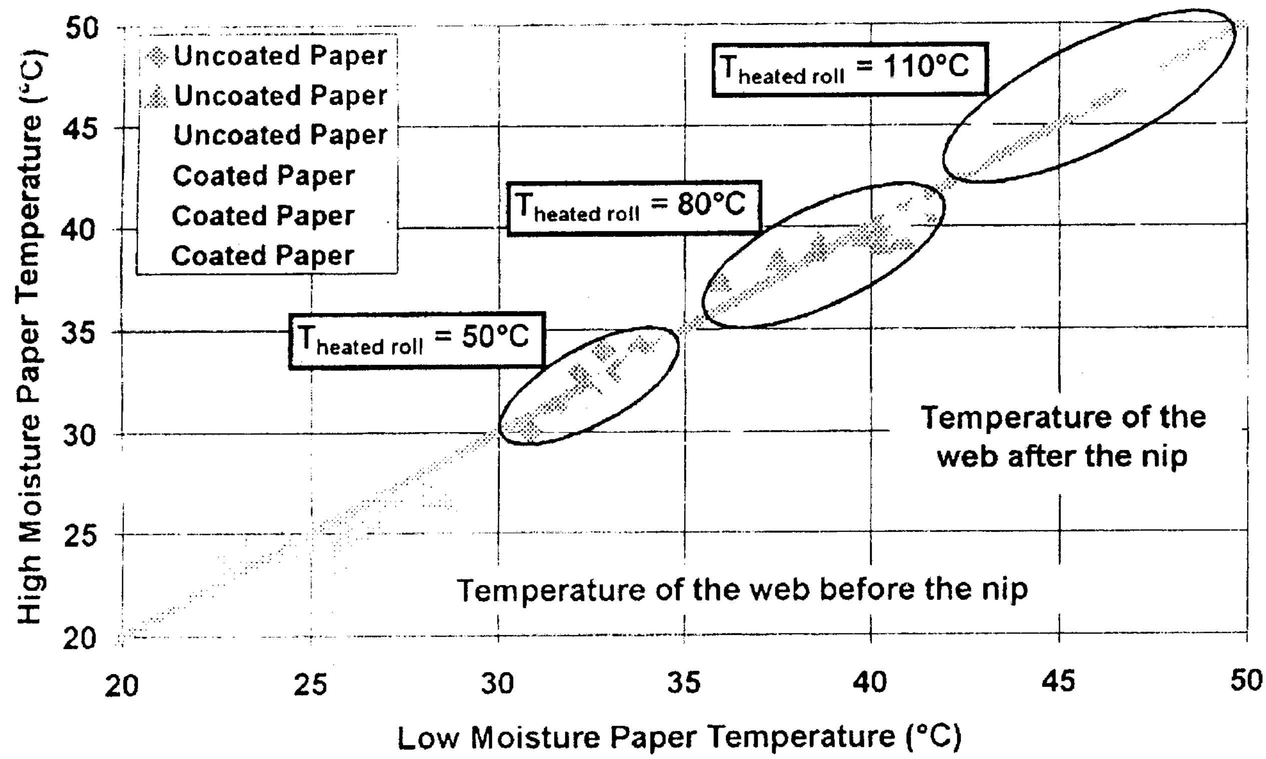

Fig. 2 Effect of moisture and coating on paper average temperature, before and after calendering.

Table-3 Ingoing nip paper average temperature for all the trials. Maximum standard deviation for these measurements is 0.9°C.

Heated roll Temperature (°C)	Uncoated Paper		Coated Paper	
	Moisture (%)	Ingoing nip paper average temperature (°C)	Moisture (%)	Ingoing nip paper average temperature (°C)
50	4.5	22.5	3.5	24.4
	6.5	22.6	4.8	23.8
80	4.5	25.2	3.5	25.9
	6.5	24.3	4.8	25.1
110	4.5	28.2	3.5	26.7
	6.5	26.5	4.8	25.7

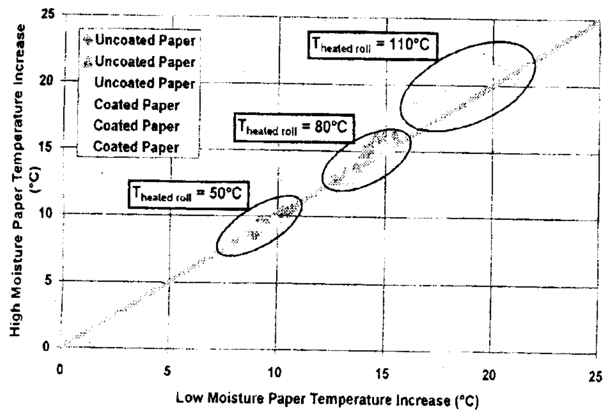

Fig. 3 Effect of moisture and coating on paper temperature increase in a nip.

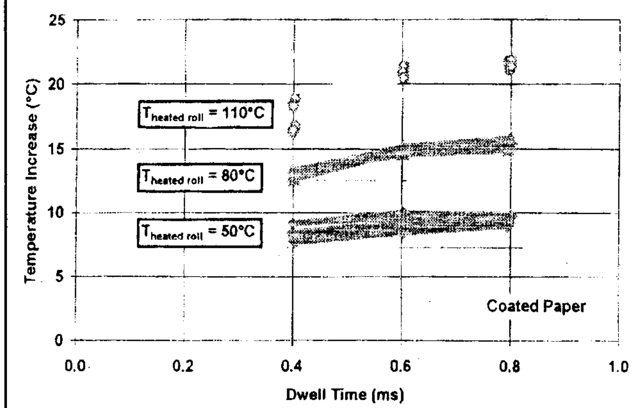

Fig. 5 Effect of dwell time on temperature increase of coated paper during calendering.

of our parameters on the web temperature increase in the nip. i.e. the difference between the temperature of the web measured after the nip and the temperature of the web measured before the nip (Fig. 3).

Considering the heat transfer in the nip, the temperature level of the heated rolls seems to be the most important parameter of all those studied here. Fig. 3 actually shows three distinct groups of measurements depending on the temperature of the heated roll. Moreover the elevation of temperature experience by the paper web in the nip is almost the same when comparing uncoated and coated paper. But the transfer of thermal energy is better in the case of coated paper because the amount of heat transferred from the rolls to the paper is higher in the case of coated paper. The specific heat per unit of mass of the uncoated paper is (16) actually about 1.2 J/(g.K) and the specific heat per unit of mass of the coated paper is 1.13 J/(g.K). So the specific heat for the 60 g/m² uncoated paper is 1.2 J/(g.K) x 60 g/m² = 72 J/K and the specific heat for the 81 g/m² coated paper is 1.13 J/(g.K) x 81 g/m² = 92 J/K. The variation of heat capacity due to variation of water amount is not taken into account here. The amount of heat accumulated by the paper web is calculated from the specific heat and the temperature increase. As the temperature increase is nearly the same between uncoated and coated paper, the differece in the specific heat makes the difference in heat accumulated by the paper web. So the presence of coating layer improves heat transfer in a nip, which seems quite normal so far as the coating layer has a thermal conductivity that is three to four times higher than the thermal conductivity of an uncoated paper (17).

These calendering trials also enable studying the effects of dwell time on paper temperature increase during calendering for an uncoated paper (Fig. 4 and for a coated paper Fig. 5). In Fig. 4 and Fig. 5, we observe that the

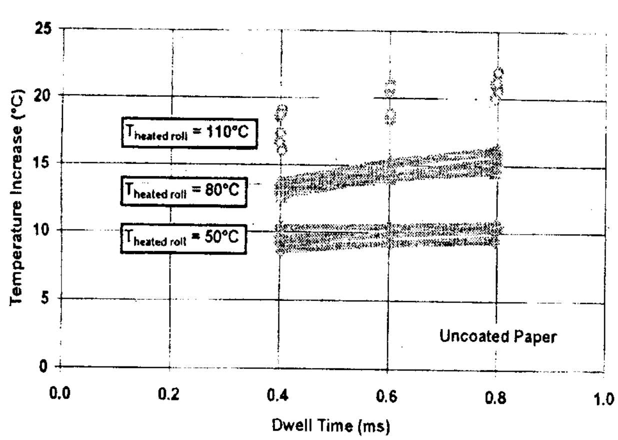

Fig. 4 Effect of dwell time on temperature increase of uncoated paper during calendering.

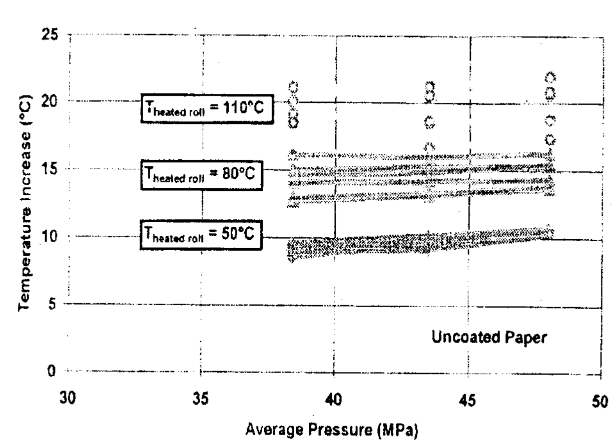

Fig. 6 Effect of average pressure on temperature increase of uncoated paper during calendering.

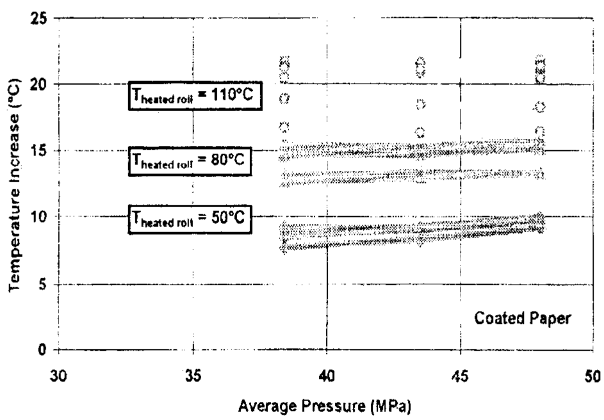

Fig. 7 Effect of average pressure on temperature increase of coated paper during calendering.

longer the dwell time, the higher the paper temperature increase in a nip, and the higher the temperature of the heated roll, the stronger the effect of the dwell time, That is quite normal, if we look at the solution of the heat transfer equation in a nip (13,16).

If we look the effects of pressure on paper temperature increase during calendering (Fig. 6 and Fig. 7), we observe that the pressure has only a very small effect on the paper temperature increase. An increase of pressure leads to a small elevation of paper temperature increase in the nip. The lower the temperature of the heated roll, the stronger is the pressure effect. If we assume that the higher the pressure, the higher the compression of the paper in the nip, the results mean that either the variation of the paper thermal properties (particulary thermal diffusivity) with the pressure is negligilbe in the heat transfer in a nip or the thermal properties of the paper are independent of the pressure in the considered range. Furthermore, some authors take into account a contact resistance between the rolls and the paper in evaluating heat transfer in the nip (14, 18). The results founded in this study suggest that either the contact resistance is independent of the pressure, or that there is no thermal contact resistance at this level of pressure. This last conclusion corresponds with the results founded by Sanders (19).

CONCLUSION

If we consider heat transfer in a nip, the level of temperature of the heated rolls seems to be the most important parameter of all those studied here. The effect of dwell time on heat transfer quite agrees with what we were expecting from the theory: the logner the dwell time, the higher the paper temperature increase, and the higher the temperature of the heated roll, the stronger is the effect of the dwell time. If we look at pressure effect, at a constant dwell time, we observe that pressure has only a very small effect on paper temperature increase. Considering the paper parameters, it appears that the moisture level (in the considered range) does not seem to have an effect on the web heating in a nip whether the paper is coated or not. Moreover the elevation of temperature undergone by the paper web in the nip is almost the same when comapring uncoated and coated paper but the transfer of thermal energy is better in the case of coated paper. This work will be completed with a comparison between the practical values of temperature measured and the calculated temperature from a theoretical model. It will also be continued with an analysis of parameters influencing thickness reduction. Then some additional trials will give clues to understanding the effect of coat weight and the number of nips on heat transfer and thickness reduction of paper during calendering..

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