

AN INSIDE VIEW ON IMPULSE DRYING PHENOMENA BY MODELLING

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ABSTRACT

This paper describes the first phase of the development of a press model called EXPRESS. The model is used to support the R&D activities in Europe on improved mechanical dewatering. The basis is a currently one dimensional press model describing the flow phenomena in a sandwich formed by the paper web and the press felt(s). The model has been extended with an energy equation describing the heat transfer in a heated press nip. Ultimately the model will be capable to describe the impulse drying process.

EXPRESS-1, the result of phase 1, has been validated with experimental data from a pilot paper machine shoe press operated with press roll temperatures from 50°C up to 235°C. The model predictions show good agreement with the experimental data over the whole temperature range. This implies that the model already can be used as a tool to predict the performance of a normal shoe press, when it will be operated at futuristic high roll temperatures.

INTRODUCTION

The process of wet pressing has been studied over decades and still there are many theories about the mechanisms under discussion. The reason is the length scale and time scale in which the process takes place. Over a nip distance of a few centimeters and a thickness of a few 100 microns water is squeezed out of the paper web in milliseconds. Performing accurate experiments is therefore very complicated. Furthermore access to at least a (full speed) pilot machine is required to study the dynamics of the process in the right time scale.

An even more complex pressing process is the impulse drying process, where wet pressing is enhanced by applying excessive heat through a heated press roll with temperatures up to 300°C. Many aspects of this process have been studied now for more than 20 years by researchers in Europe as well as in North America. Especially at IPC, later IPST the impulse drying process has been studied intensively by a.o. Orloff [1], who published many papers on this subject. Van Lieshout [2] made a complete historical overview of the impulse drying research.

In Europe recently a new research program has been started to study impulse technology at the pilot scale. To enhance this experimental program we started a model development program based on a combination of “first principles” physics and “accepted” empirical theories. Validation, based on comparisons between modeling results and experimental results obtained from the pilot machine trials, will show the accuracy of the adopted theories to describe the phenomena. In this respect the model will form a good basis for discussions between “theoretical groups” and “experimental groups” of scientists active in the field.

WHAT IS WET PRESSING?

Figure 1 shows schematically the pressing process in a roll press. The paper web is squeezed together with one or more press felts between two rolls exerting a mechanical pressure on the web and felt. In the compression phase water will flow from the web to the felt forced by a positive hydraulic pressure gradient. At the end of the press nip when the mechanical pressure decreases, the hydraulic pressure gradient will become negative resulting in some rewet, caused by a back-flow of water/air from the felt to the web.

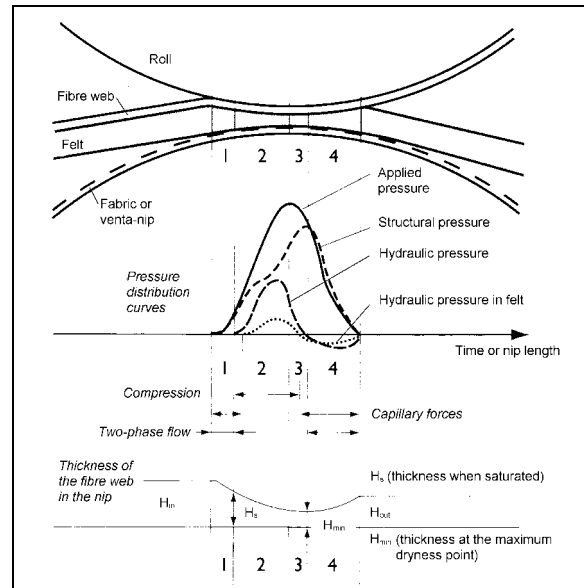


Figure 1. Wet Pressing in a Roll Press from [3].

THE SCOPE OF EXPRESS-1

EXPRESS-1 is the result of the first phase of the model development program. It describes the transversal flow in the paper web and the press felts under a mechanical pressure exerted in the press nip. In case of a heated press roll the model calculates the energy transport from the press roll to the paper web. This energy transport is also assumed to be one-dimensional in a direction perpendicular to the sheet surface. The potential of the model is to calculate the sheet dryness at the end of a press nip given a mechanical pressure curve and temperature of the press roll. The model also predicts the amount of in-nip rewet which will occur at the end of the press nip, because of web and felt expansion. In case of “impulse drying” press nips, with press roll temperatures above 100°C flash expansion at the end of the press nip might cause delamination of the paper web. Based on the calculated temperature gradient the model indicates to what extent the web will expand as a result of flashing, showing the severity of the impact and the chance on the occurrence of delamination. Therefore EXPRESS-1 can be used as a tool to evaluate methods to reduce the effect of flash expansion.

The Geometry of the EXPRESS-1 Model Domain

The geometry of the calculation domain of the model is shown in **Figure 2**. It consists of the sandwich formed by the paper web and felt in contact with the (heated) press roll. Since the press roll itself is part of the calculation domain the model will also calculate the temperature distribution in the roll during the pressing operation. The thickness of the roll in the model domain is chosen in such a way that the roll temperature at the top boundary is constant during the whole process (approx. 15 mm).

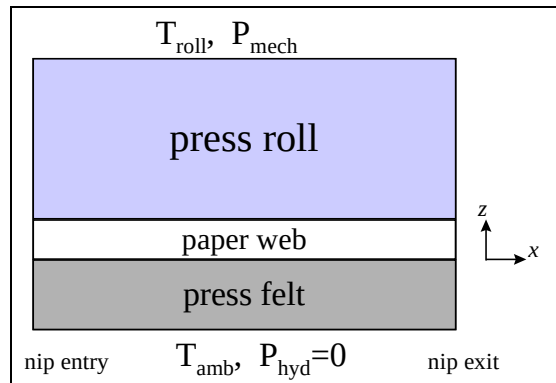


Figure 2. Schematic View of the Geometry of the Model Domain of EXPRESS-1.

Model Output

The model will calculate the following data:

- Sheet dryness after the press nip.
- Sheet thickness after the press nip.
- Sheet temperature after the press nip.
- Moisture ratio distribution in the paper web and the press felt in the (x,z) plane.
- Temperature distribution in the press roll and the paper web in the (x,z) plane.
- Maximum sheet dryness in the nip.
- In-nip expansion rewet of the paper web.
- In-nip flash expansion in case of impulse drying conditions.
- Energy transfer from the press roll to the web in case of a heated press roll.
- Efficiency of the wet pressing operation.

BACKGROUND THEORY

In this section we will discuss some background theory of the EXPRESS-1 model.

The model has been based on the following basic assumptions:

- The calculation domain consists of the sandwich formed by the paper web, the press felt, and the press roll.
- Paper web enters the nip fully saturated.
- Press felt has a uniform initial dryness between 0 - 100%.
- The press felts are assumed to compress and expand immediately under application of an external mechanical pressure, which means neglecting viscous, or visco-elastic behaviour of the press felts.
- In a double felted press nip the geometry is assumed to be symmetrical, i.e. only the upper half of the space domain is taken into account under assumption of no-flow through the symmetrical plane.
- The hydraulic (fluid) pressure at the interface between press felt and the roll- or belt-surface is assumed to be zero, which means that the water is assumed to leave the nip area in the felt without resistance in case of a fully saturated press felt.
- Only transversal flow is taken into account.
- Only transversal energy transport is taken into account.
- The energy transport is determined by conduction and convection in the sandwich formed by paper web and press roll.
- The energy transport from the paper web to the press felt is described by a Robin type boundary condition, specifying an external temperature in combination with a heat transfer coefficient, representing the heat resistance of the press felt.
- The hydraulic pressure is equal for air and water, i.e. capillary effects are neglected.
- The fibers, the fluid, and the press roll are incompressible.

- The existence of bound water in the fibers is taken into account implicitly in the compressibility function.
- The compressibility of the paper web follows a different curve for increasing and decreasing nip pressures and may show some permanent deformation.
- The compressibility is independent of temperature.

Some aspects of the model will now be highlighted.

Wet Pressing is a Flow Through a Deformable Porous Structure

The basic idea behind all wet press models is that through application of an external mechanical pressure on a deformable paper web, a flow of water will be generated by a hydraulic pressure gradient. Since the water flows through a porous structure, the relation between the flow velocity and the hydraulic pressure gradient is assumed to be linear in accordance with Darcy's law. The magnitude of the flow velocity at a given pressure gradient is determined by the permeability of the porous structure and the viscosity of the fluid. The more open the porous structure is, the higher the permeability will be and the more easily water will flow through the structure, resulting in fast dewatering of the sheet, giving a higher sheet dryness after the press. Also a low water viscosity will improve the dewatering speed, because the water will flow more easily through the structure. Since viscosity of water decreases when temperature increases, an increase of the process water temperature will enhance the press performance.

During dewatering of the sheet by compression the porous structure will become more dense, which means that the porosity will decrease and as a consequence also the permeability of the sheet will decrease. So if the moisture ratio decreases the dewatering process will slow down. The relation between permeability and moisture ratio is mathematically described by a power law function as found by Nilsson [4].

Compressibility

The paper web consists of a porous structure formed by fibers. If an external force is exerted on this structure the fibers will bend and form a more dense compacted structure until the structural pressure of the web balances the externally applied pressure force. To a certain extent this process is elastic. The relation between the structural pressure and the deformation is called the compressibility function. Actually this is described by a non-linear stress-strain relation. It has been found by Nilsson [4] that the relation between the structural pressure and the moisture ratio is mathematically described by a power law function. This type of relation is valid for paper webs as well as for press felts and textiles.

Dewatering Coefficient

During the wet pressing operation the web structure will be compressed and as a consequence structural pressure will be built up. The difference between the externally exerted mechanical pressure and the structural pressure of the paper web is the hydraulic pressure of the fluid, which is the driving force for the water flow through the paper web. This implies that both permeability and compressibility strongly influence the dewatering behavior of the paper web in the press nip. By mathematical analysis the governing equations can be transformed into a single non linear diffusion equation for the moisture ratio or the void ratio, (which is the ratio between void volume and solid phase volume), of the paper web. The non-linear diffusion coefficient in this equation is called the dewatering coefficient. For a detailed derivation of these equations, see Riepen [5].

Dynamic Felt Model

The dynamic behavior of the felt during the wet pressing operation is described in the same way as the paper web, i.e. by a compressibility function and a permeability function. The difference with the approach used for the paper web is the omission of viscous effects inside the felt itself during compression and expansion. The felt is assumed to respond to changes in the applied mechanical pressure immediately. Since the permeability of the felt is at least a factor 100 greater than the average permeability of the web, this is a fair assumption in comparison to the viscous effects in the paper web itself.

The compressibility of the felt is described by the model proposed by Österberg [6], which is in fact the same type of power law function as used to describe the compressibility of the paper web. Different parameters are used for compression and expansion of the felt, taking into account hysteresis effects.

The hydraulic pressure drop over the felt is determined by the permeability of the felt, which is described by a traditional Carman-Kozeny equation, and the actual thickness of the compressed felt. Also the saturation of the felt is

taken into account. For the description of the saturation in the felt two models have been implemented. These models can be selected independently and will be described below.

In the compression phase of the pressing operation both models operate in the same way. In this approach all water emerging from the web surface will fill up the void volume inside the felt up to 100% saturation starting from the web interface towards the roll surface. This void volume is determined by the initial saturation of the felt, which is assumed to be uniformly distributed over the whole thickness of the felt and of course the state of compression. In this approach all the water removed from the paper web is assumed to be collected on top of the felt/web interface, until saturation is reached. If the felt becomes completely saturated during the wet pressing operation then it is assumed the water can leave from the roll side without additional resistance, for example through grooves.

In the expansion phase two models can be selected for the water transport inside the press felt:

- I. Water stays at the felt/web interface during expansion, assuming low forces between the felt fibers/yarns and the water (**Figure 3**).
- II. Water will move upwards with the expanding felt structure assuming strong forces between the felt fibers/yarns and the water (**Figure 4**).

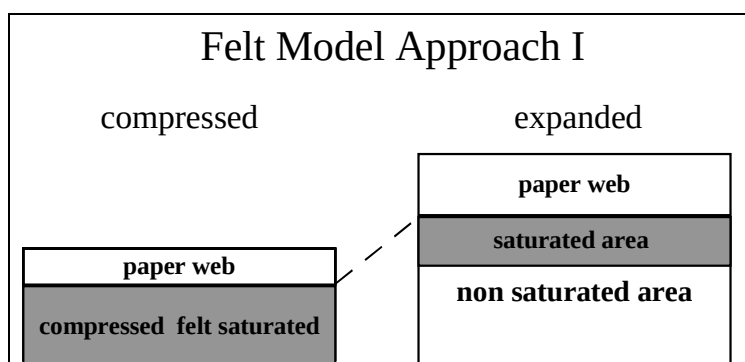


Figure 3. Schematic View on Felt Model Approach I.

In approach I a thin layer of water at the felt/web interface will create a significant hydraulic pressure drop resulting in a limited rewet back flow. But the saturation of that back flow is 100%, so the total rewet can be significant.

In approach II the felt pores at the interface will be non saturated. This will cause a lower pressure drop over the felt resulting in a higher back flow towards the paper web during expansion. However, since this flow is non- saturated the net flux of water might be lower.

In practice the situation will be a weighted combination of approaches I and II. From experiments the weighting factor can be estimated.

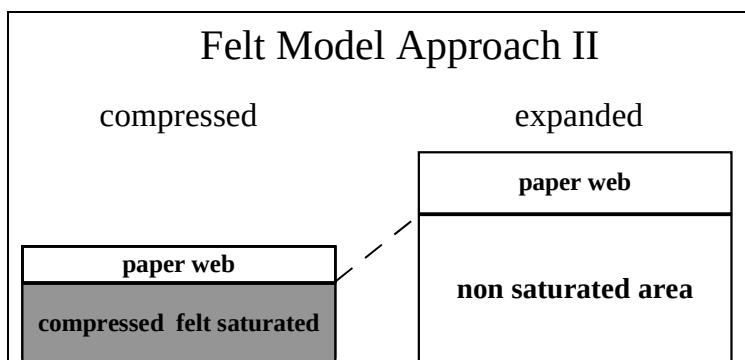


Figure 4. Schematic View on Felt Model Approach II.

Heat Transport

In case of applying a heated press roll an energy flow from roll to paper web will be established at the moment the web makes contact with the press roll. In EXPRESS-1 it is assumed that the contact between the heated press roll and the paper web is complete, without inclusion of air. In this case the contact temperature at the interface is completely determined by the thermal properties (heat conduction coefficient and thermal diffusion coefficient) of the paper web and the press roll material. Since we calculate the heat transport in the roll as well as in the paper web simultaneously, by solving a partial differential equation, no special treatment of the web/roll interface is required. By using a conservative finite volume approach the contact temperatures at interfaces of cells with different thermal properties are calculated physically correct. This means that the temperature at the interface between two cells is determined in such a way that the heat flux through the cell interface is equal for both the cells.

In the press roll the heat transport is completely determined by heat conduction. The upper boundary is put far from the web/roll interface, which allows prescribing a constant temperature not affected by the pressing operation itself.

In the paper web heat conduction is also important for energy transport. The heat conduction coefficient depends on the moisture ratio of the web, with as limit value the heat conduction coefficient of water.

Besides the energy transport through conduction, transport through convection is also important. The water in the web heated near the press roll surface will move in the direction of the press felt during the pressing operation. It will exchange its heat with the fibers while passing through the porous structure. The more a sheet is compressed the more water will be transported from the hot roll side to the cold felt side and the more heat can be converted from the roll to the web. So the temperature distribution in the paper web depends on the dewatering behavior.

As already mentioned, the dewatering behavior is influenced by the viscosity of the water flowing through the porous structure. This water viscosity depends strongly on the temperature, which makes this heated mechanical dewatering process a strongly non-linear process. Since the thermal properties of the press felts are unknown at the moment it was decided to describe the heat transfer to the press felt by a boundary condition at the web/felt interface. The Robin type boundary condition is defined by a heat transfer coefficient and a temperature, representing the temperature of the felt far away from the web/felt interface. This temperature is assumed to be constant during the wet pressing operation. If the thermal properties of the press felts are known the model can be extended in the same way as the heat exchange between press roll and paper web is treated.

Flash Behavior

It is assumed that the fluid domain is in thermal equilibrium. This implies that if the temperature in the water filled pores exceeds the boiling point at the local (intrinsic) hydraulic pressure, liquid will evaporate until the hydraulic pressure in the pore balances the saturated vapor pressure at the fluid temperature. So temperature and hydraulic pressure are coupled through the vapor pressure equation of Clapeyron.

In the expansion phase the applied mechanical pressure will decrease. The result will be that the web will expand according to the semi-elastic stress balance. In normal (cold) wet pressing the web can only expand as fluid fills up the created void volume, because otherwise vacuum will be created inside the pore. This fluid has to come from adjacent parts of the porous structure forced by a hydraulic pressure gradient. This process requires time and limits expansion and is experienced as viscous damping. However, when temperatures in the web are above 100°C, the expansion will be forced by quick evaporation, *flashing*, until the sum of the structural pressure and the hydraulic pressure balance the applied pressure. The created void volume will now be filled with vapor evaporated from the liquid in the pore itself. This process can go very quickly and is therefore referred to as *flash expansion*. If the flash expansion exceeds certain limits delamination of the sheet may occur. In that case the vapor will force a breakthrough to the sheet's surface and the evaporation will continue until the sheet temperature is about 100°C, where the saturated vapor pressure equals atmospheric conditions. This high vapor flow may damage the structure of the paper web and is one of the major problems in applying impulse drying in practice.

To get a first impression of this effect a simple relation has been added to the EXPRESS-1 model. This relation will show how much expansion can be expected in the web based on the local temperature distribution in the web during the expansion phase. In this approach it is assumed that the web structure can also absorb tensile stress to a certain extent. In practice this ability will also depend on the evaporation speed. This is a complex process that will be studied in later phases of Europress-Masterpress.

MODEL VALIDATION

In order to get a view on the validity of the assumptions used for EXPRESS-1, the results of one impulse drying trial were selected for comparison with simulation results. In this trial a basis weight of 80 g/m² was produced at a machine speed of 600 m/min.

The first two presses in the press section of the pilot machine were operated at constant temperature without additional press roll heating. The last shoe press was operated at three different press loads (400, 600 and 800 kN/m) and with 5 different temperatures (50, 95, 135, 200, 235°C). For each combination of press roll temperature and press load an average increase of the dry solids content, the sheet dryness, was measured with online sensors. All measurements were taken after the sheet had left the press nip, so it is unclear how much evaporation and rewet occurred between the nip opening and the sensor positions.

Table 1 shows that in this specific case pressing with a heated shoe press with a roll temperature of 235°C results in an increase of the sheet dryness of about 8% point in comparison with normal wet pressing with similar press load.

Table 1. Results of non-confidential trial at the pilot paper machine with press roll temperature Troll in the range from 50°C to 235°C.

Basis_weight [g/m ²]	Roll Temp [°C]	Press load [kN/m]	DS in [%]	MR in	DS out [%]	MR out	MR decrease
75.4	50	400	36.4	1.75	41.6	1.41	0.34
77.3	50	600	36.4	1.75	42.9	1.33	0.42
77.5	50	800	36.4	1.75	43.6	1.29	0.46
76	95	400	36.4	1.75	43.2	1.31	0.44
76.6	95	600	36.4	1.75	44.2	1.26	0.49
76.4	95	800	36.4	1.75	45.9	1.18	0.57
77.5	135	400	36.4	1.75	44.4	1.25	0.5
78.5	135	600	36.4	1.75	45.5	1.2	0.55
76.8	135	800	36.4	1.75	47.4	1.11	0.64
78.1	200	400	36.4	1.75	46.6	1.15	0.6
77.3	200	600	36.4	1.75	47.9	1.09	0.66
77.5	200	800	36.4	1.75	49.3	1.03	0.72
77.8	235	400	36.4	1.75	48.6	1.06	0.69
75.2	235	600	36.4	1.75	50.0	1	0.75
75.6	235	800	36.4	1.75	52.1	0.92	0.83
78.5	235	800	34.08	1.93	50.8	0.97	0.96
75.9	235	800	37.25	1.68	52.1	0.92	0.76
77.8	235	800	38.1	1.62	51.9	0.93	0.69
78	235	800	36.4	1.75	51.5	0.94	0.81

The pressure curve applied by this heated shoe press has the following shape shown in **Figure 5**.

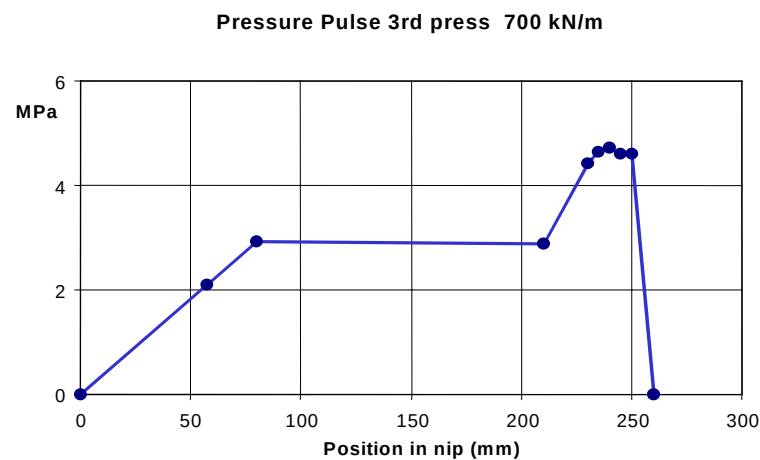


Figure 5. Pressure Pulse Curve of Shoe Press (courtesy STFI).

This pressure curve is flat over a length of about 130 mm, which is half the nip length and has a hammer near the end of the nip. The idea behind this curve shape is that during the first part of the nip the dewatering process is flow controlled. Increase of pressure will only have a small impact on the dewatering speed. Near the end of the nip the dewatering might become pressure controlled. In that case an increase of the applied pressure is much more effective. The consequence of this curve is that at the end of the press nip the pressure drop is very sudden and the gradient is really high. So from the perspective of delamination in impulse drying such a steep pressure decrease might be less favorable.

Product Characterization

Before we could start with the simulation of the above trials we first had to characterize the product made at the pilot machine.

Structural Pressure

The structural pressure function was determined with a compressibility measurement at the TNO laboratory. For this measurement 15 samples of dried product are re-wetted and thereafter statically pressed in a compression cell at different mechanical pressures varying between 5 and 50 bar. The result is a pressure curve as defined by the formula:

$$S = 3.78 X^{-5.15}, \text{ with:}$$

S = structural pressure [MPa]

X = void ratio (ratio between void volume and solid phase volume) [-]

This structural pressure function has been kept constant over the whole temperature range.

Figure 6 shows the structural pressure as function of sheet dryness. This figure has to be interpreted in the following way. If a paper sample is put under a static mechanical pressure of for example 1 MPa (10 bar), then a final dryness of 55% will be achieved after a period which is long compared to pressing times and short enough to avoid creeping effects. In practice the required time for stabilization is about 3-5 minutes. A practical limit for the compression is reached at approx. 65% dry solids content, which requires a mechanical pressure of 10 MPa.

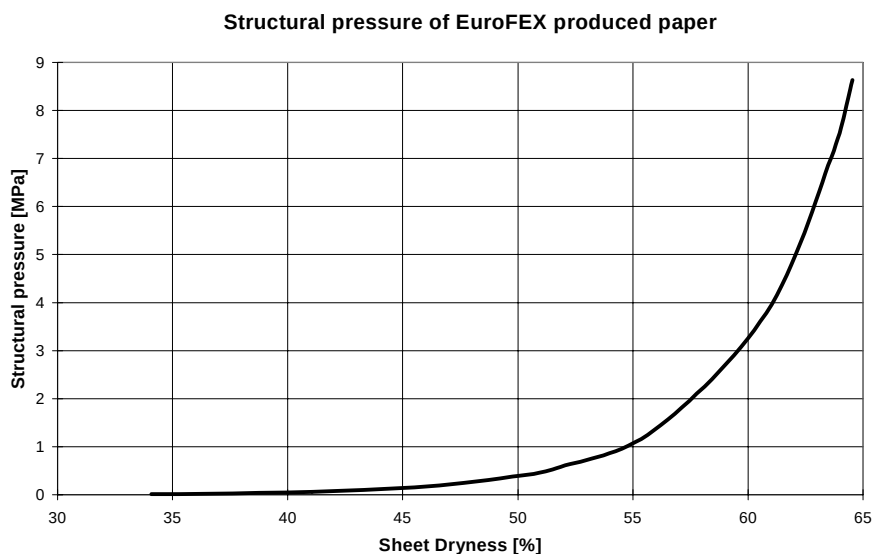


Figure 6. Structural Pressure of Paper (sulphate) Produced with Pilot Paper Machine.

Permeability

The permeability function was based on literature references as first approximation and were adjusted during the simulations. Finally all simulations have been performed with the following permeability function:

$K = 3.4 \times 10^{-18} X^{3.7}$, with:

K = permeability [m^2]

X = void ratio [-]

Figure 7 shows the permeability as function of the sheet dryness for the range covering the experiments. The permeability varies in this range over a decade.

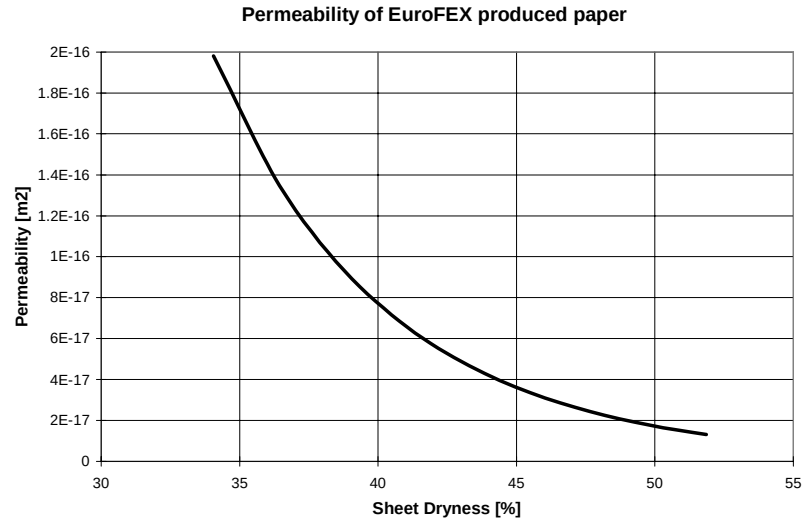


Figure 7. Permeability of 80 g/m^2 Paper (sulphate) produced with Pilot Machine.

Validation Procedure

The permeability function of the paper web was used for tuning the simulations with the experimental data. To match the measured values of the sheet dryness after the heated press, the parameter A in the permeability function was adjusted.

$K = A X^{3.7}$, with:

K = permeability [m^2]

X = void ratio [-]

The stop criterion for the automatic tuning process was an absolute difference between the calculated and measured dryness of 0.3% of sheet dryness. In the figure below the results of this tuning process has been summarized for all cases:

Figure 8 shows that only 3 of the 19 test runs require a correction of more than 15% relative to the reference value of A , which is the average value of A taken over the 16 “reliable” test runs. This is a remarkably good result since experiments will suffer from inaccuracies and the model depends on many assumptions. If we neglect these 3 runs then the standard deviation on parameter A is less than 8%.

After this tuning process all case runs have been repeated with the reference value of parameter A : $A_{ref} = 3.4 \times 10^{-18} \text{ m}^2$. The results are shown in.

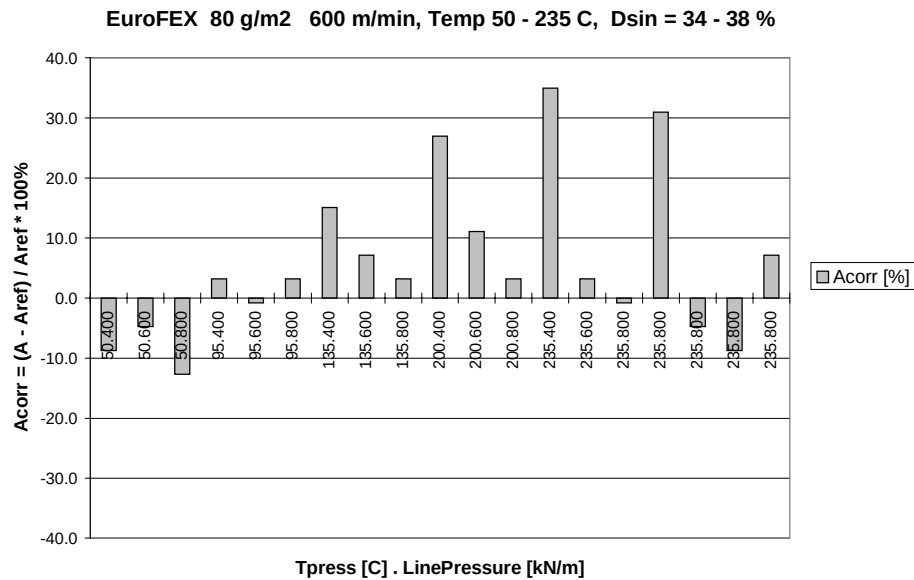


Figure 8. Correction on Permeability Parameter A Relative to the Reference Value
 $A_{ref} = 3.4 \times 10^{-18} \text{ m}^2$.

Figure 9 shows that the calculated dryness is not very sensitive to the tuning parameter A. The average absolute difference between the calculated dryness and the experimentally determined dryness is 0.74% point based on the 16 reliable test runs. In **Figure 10** the EXPRESS-1 simulations are compared with the experimental data of the pilot machine trial. Each point represents a test run. The deviation of a point from the solid line is an indication for the mismatch between the calculation and the measurement.

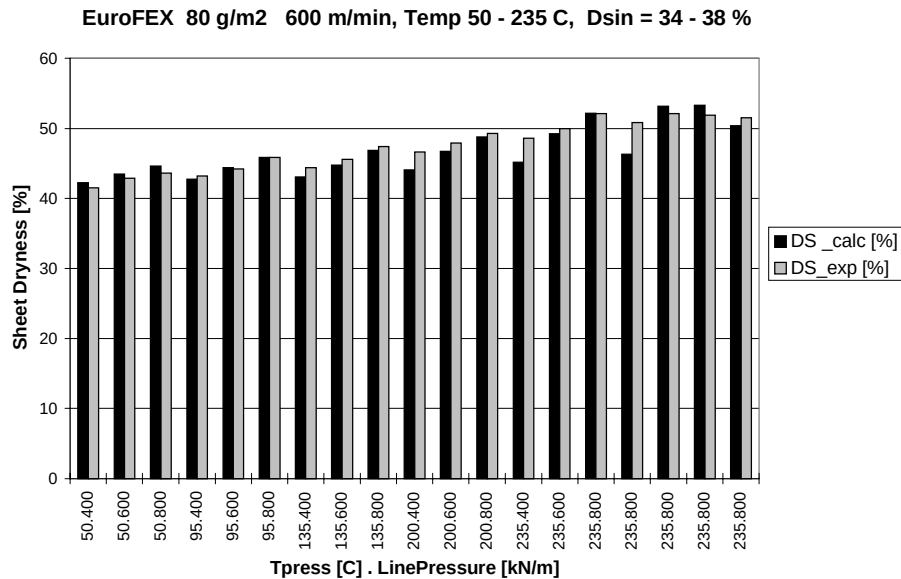


Figure 9. Comparison between Experimental Data and Model Data for a Trial on the Pilot Paper Machine.

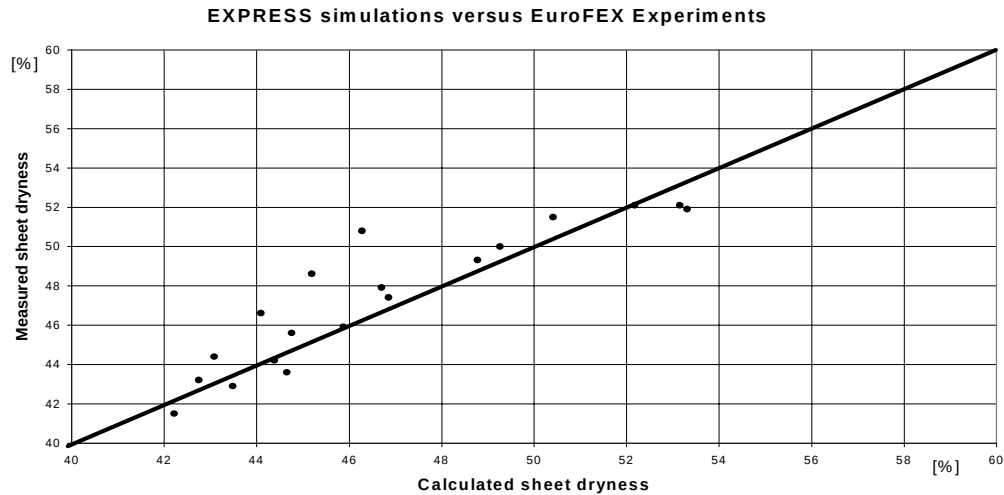


Figure 10. Comparison between the Simulation Results determined with EXPRESS-1 and the Experimental Data from the Trial shown in Table 1.

OBSERVATIONS BASED ON EXPRESS-1 SIMULATIONS

Although extensive validation still has to be performed for other basis weights, machine speeds and products, the model can already be used to get a qualitative view on what might be happening during an impulse drying test run. To analyze the phenomena we compare two test runs both with press load 800 kN/m. In the first test run the roll has a temperature of 50°C, an almost normal wet pressing trial referred to as test run 1, and in the second test run the press roll has been heated up to 235°C, a real impulse drying trial referred to as test run 2. Results of these simulations are shown in **Figure 11** and **Figure 12**.

Sheet Warming-Up

In both cases the sheet enters the press nip with a temperature of 30°C. Warming up will be initially dominated by heat conduction through the paper web, a process that requires time. Since the nip residence time is very short (26 ms) the heat penetration through the web is still in progress near the end of the nip. At a position 200 mm from the nip entrance the sheet surface temperature at the web/felt interface is about 34°C in test run 1, an increase of only 4°C. For test run 2 the web/felt interface has a temperature of approx. 75°C, an increase of 45°C.

Observation 1

A low viscosity of the water is very beneficial for efficient dewatering, because it reduces the flow resistance. The higher the temperature the lower the water viscosity. Since the flow of water has to pass the web through the web/felt interface the temperature near that interface has a major influence on the water viscosity and thus on the flow resistance. In Figure 11 an increase of the dewatering speed can be noticed in the last part of the nip, because the temperature near the web/felt interface increases quickly in that part of the nip from 75°C to values of about 100°C. Actually the warming up process should start from the felt side towards the roll side to be efficient. Then improved dewatering can be achieved with rather moderate temperatures.

Steam Generation during Compression

One of the explanations for the improved mechanical dewatering process is the build up of an additional hydraulic pressure by evaporation of water during the compression phase of the wet pressing operation. This effect can only occur when the temperature of the web locally exceeds the “boiling temperature” at that local hydraulic pressure in the pores of the web. In **Figure 13** we can see for example that at a hydraulic pressure of 1.6 MPa the boiling temperature of water is 200°C.

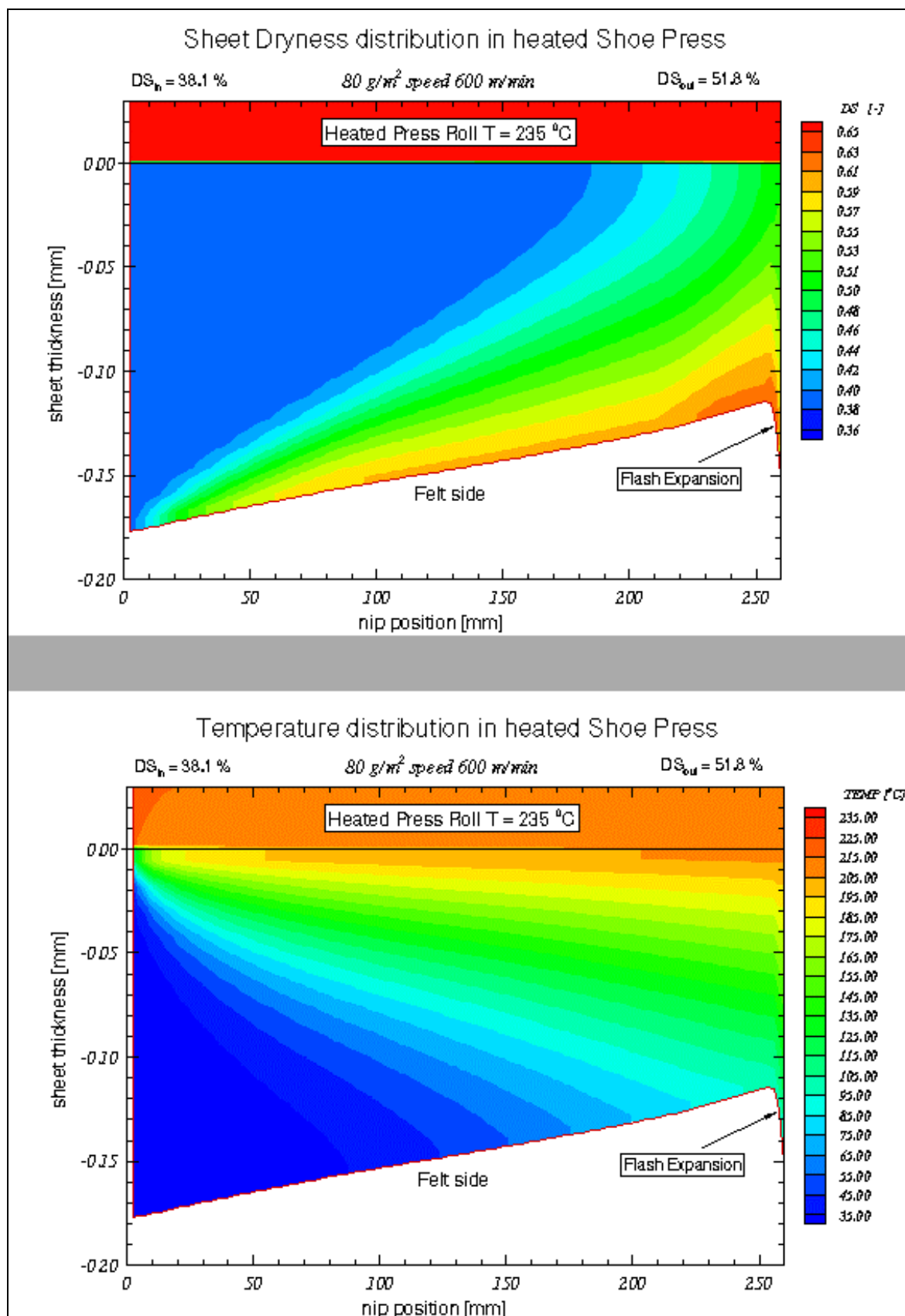


Figure 11. Simulation Result for Test Run 2 with Press Roll Temperature Troll = 235°C .

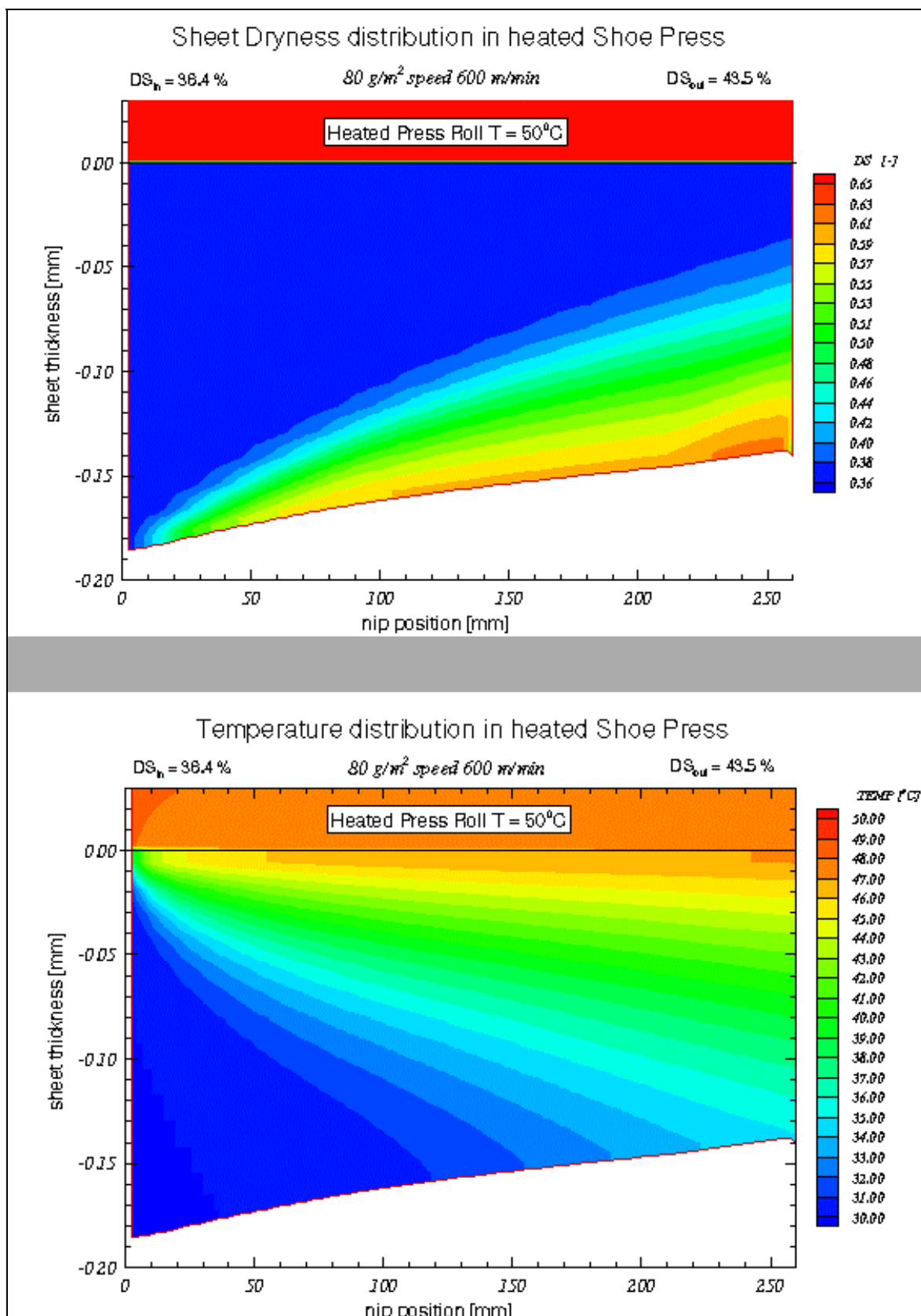


Figure 12. Simulation Result for Test Run 1 with Press Roll Temperature Troll = 50°C .

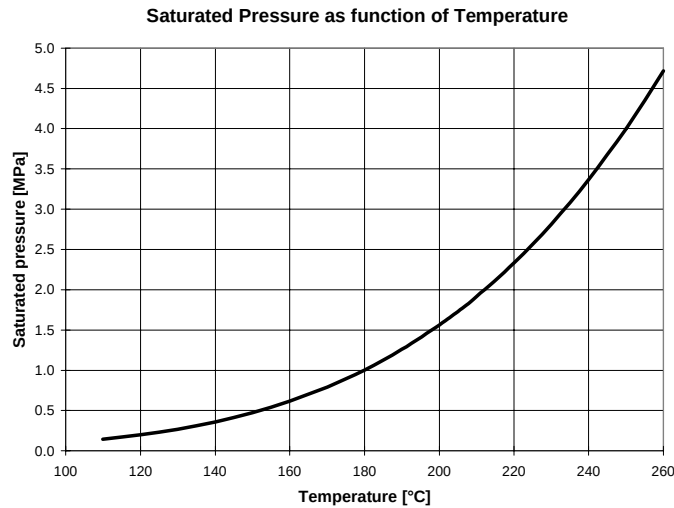


Figure 13. Saturated Steam Pressure as function of Temperature.

In test run 2 with a heated press roll temperature of 235°C the maximum temperature in the sheet is close to 205°C, which means that only if the hydraulic pressure decreases below 1.7 MPa, evaporation might occur.

The hydraulic pressure inside the paper web is according to Terzaghi's principle, see Kataja [7] defined by:

$$P_H = P_T - P_S,$$

with:

$$\begin{aligned} P_H &= \text{the hydraulic pressure [Pa]} \\ P_T &= \text{the total mechanical pressure [Pa]} \\ P_S &= \text{the structural pressure [Pa]} \end{aligned}$$

The distribution of the sheet dryness in the nip in Figure 11 shows the local sheet dryness in the area with temperatures above 200°C has a maximum of 51%. In this case the structural pressure is on the order of 0.5 MPa (Figure 6). So it may be concluded that evaporation effects can occur only if the total applied pressure in that area is lower than 2.2 MPa. From Figure 5 it follows that in the shoe press nip the pressure is constant between nip position 80 to 210 mm. In case of a line load of 400 kN/m the applied pressure in this part of the nip will be about 1.7 MPa. This implies that at a low press load steam can be generated in the compression phase of the pressing process, but that for line loads of 600 kN/m and 800 kN/m this effect is not to be expected. In the latter two cases the mechanical pressure in the nip between 80 and 210 mm is respectively 2.5 MPa and 3.5 MPa.

The effect of steam generation will be a local increase of the hydraulic pressure in the pores, which in turn will enhance the water flow through the sheet. However, this effect of evaporation in the compression phase was not included in the current version of EXPRESS-1. It might be an explanation for the high correction values needed on the permeability function for the trials with a press load of 400 kN/m and press roll temperatures of 200°C and 235°C.

Observation 2

Steam generated inside the sheet may enhance the dewatering process especially at low press loads (400 kN/m). At higher press loads the hydraulic pressure in the sheet will be high enough to avoid evaporation inside the sheet at press roll temperatures up to 235°C. Since the saturation pressure increases rapidly with temperature an increase of the press roll temperature above 250°C will enable steam generation also for higher line loads.

Flash Expansion

At the end of the press nip the mechanical pressure will drop steeply back to atmospheric conditions. According to the mechanism mentioned above evaporation will occur when the saturated pressure associated with the local temperature in the sheet will exceed the hydraulic pressure. The consequence of the steam generation is that the sheet

will expand very rapidly as indicated in Figure 11. If this expansion proceeds too quickly the sheet might get damaged by delamination. In that case the steam will break through the fibrous network to the surface. Of course the physics describing this expansion process is very complex, but still this first implementation within EXPRESS-1 shows what expansion rate can be expected, based on the pressure curve and the temperature profile in the sheet at the end of the press nip.

Observation 3

The amount and severity of flash expansion depends on the temperature gradient at the start of the expansion phase of the pressing operation. The highest temperature occurs at the web side in contact with the press roll. With the application of coatings with special thermal properties, this interface temperature as well as the distribution inside the sheet can be influenced in order to reduce the effect of flash expansion. IPST has developed and patented special ceramic based press roll coatings, see for example Orloff [8].

The Effect of Press Roll Temperatures Compared

To get a view on the potential of the technology we compare the experimental results from Table 1 for runs with equal input dryness and press load, but with 50°C press roll temperature versus 235°C. For a basis weight of 80 g/m² the press dewatering performance in **Table 2** is achieved with an initial sheet dryness of 36.4%.

Table 2. Water removed (g/m²) with pilot machine shoe press operated with press roll temperatures of 50°C and 235°C for a basis weight of 80 g/m² produced with a machine speed of 600 m/min.

Press load	Troll = 50°C	Troll = 235°C	difference
kN/m	g/m ²	g/m ²	g/m ²
400	25.6	53.7	28.1
600	35.7	56.4	23.9
800	32.5	62.7	27

Observation 4

The effect of heating a press roll up to 235°C will be comparable in this specific case to one extra additional “cold” shoe press operated at the same load conditions. However it must be noted that the maximum dryness achieved in this trial test program is on the order of normal wet pressing operations using shoe presses

(50 - 52%). Based on calculations using EXPRESS-1 the amount of (electrical) energy required in test run 2 is 510 kW/m width of the paper machine. So for a normal width of about 2.5 m the electrical power required to operate an impulse press at 235°C is in the order of 1.3 MW. This number does not include all kind of energy losses in the system, it only counts for the energy required for the heating of the paper web.

CONCLUSIONS

Although the modelling work of the impulse drying process is still in a premature state it can be concluded that EXPRESS-1 forms a good basis for future extensions.

The model can already be used to evaluate test runs and can assist researchers in setting up experimental programs around the most likely useful cases.

EXPRESS-1 results form a good basis for discussions about the direction in which the wet pressing research should focus to achieve improved mechanical dewatering in a convenient way. To open this discussion we can summarise what we learned from the observations. To optimise the mechanical dewatering process with minimal energy demand it is essential to warm up the web/felt interface efficiently from the felt side to decrease the viscosity at the interface, where the water has to leave the web. This can be done with a separate heater before entering the press nip. The second way to improve the dewatering process is generating an additional hydraulic pressure by heating up the web/roll interface above the “boiling point”. This is more effective in the first part of the shoe press nip at the lower applied pressure. At the end of the nip it is beneficial to have moderate temperatures inside the web to limit the amount of flash expansion. To fulfil both demands, heating should start before the nip and should be stopped in the

last part of the nip. One option to achieve this is with a thin heated belt, which is pre-heated up to a high temperature and which is guided through the press together with the sheet and the press felt. If the contact between the belt and the web starts at a certain distance before the nip entry is reached, the temperature rise of the web inside the nip will be much faster and then the temperature of the sheet will exceed more easily the local “boiling point”. Since the pre-heated belt will cool down in contact with the sheet and the press roll, a wise selection of belt thickness, thermal properties and press roll temperature will create a temperature distribution inside the web at the end of the nip which is low enough to avoid delamination. An other advantage of this approach is that the complete press roll does not have to be heated, but only the belt, and this can be achieved with all kind of heating systems and not necessarily with electricity.

To support the R&D work on impulse drying and other improvements on advanced mechanical dewatering EXPRESS-1 can be of great help. The next step in the model development is extensive validation of the model for a broad range of process conditions. Furthermore, improvements and extensions are required to describe the physics when steam will be generated during the compression phase of the pressing operation. Finally a start has to be made with the implementation of multi-dimensional flow effects, starting with lateral flow in the press felt.

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