HIGH TEMPERATURE PRESSING OF FIBROUS MATERIALS

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Contents

Abstract

Objectives of the project

The manufacture of paper from pulp requires a large amount of energy and a major part of the energy consumption is connected with de-watering (i.e. the removal of water from the pulp) and consolidation. A number of high-temperature wet pressing processes have been envisaged which could make a major impact on the efficiency of de-watering and consolidation. The introduction of such processes in paper manufacturing is expected to result in major energy savings, more efficient use of raw materials and a considerable reduction in the capital costs of new paper machines. They will also make it possible to enhance the quality of the products and even to develop new products using chemical reactions such as cross-linking (e.g. as are utilised in medium-density fibreboard pressing). The objective of this project has been to generate the necessary scientific and technical knowledge required for the understanding of new high-temperature wet pressing processes and for the proper design and operation of such processes.

Technical approach

The objectives of the project have been achieved by a combination of theoretical analysis and experimental investigations. Experiments have been performed on both specially designed laboratory equipment and on an experimental pilot-scale paper machine (referred to as EuroFEX in this report) that has two high-temperature shoe-press units and is capable of running at the high speeds of modern paper machines.

Results achieved

A good understanding of the physics of high-temperature pressing has been achieved. This understanding has led to the development of mathematical model of high-temperature wet pressing The predictive capability of the model is quite good within the range of temperatures and linear loads of interest in high-temperature pressing. This has been demonstrated with help of data from extensive trials on EuroFEX. A calibrated model can give considerable information about changes in the state of the web as it passes through the nip. The information obtained from the model can give insights about the mechanisms that are active in the nip under specific design and operating conditions. Thus the model can be a valuable tool in the design and operation of high-temperature pressing.

The model developed requires information regarding the permeability and rheology of wet webs in compression. This information has been generated by the project with the help of specially designed equipment. In particular, two accurate permeameters (for wet fibre webs and press felts respectively) have been built. Databases have been designed containing data on permeability, rheology and heat transfer phenomena.

The original high-temperature pressing units on EuroFEX have been redesigned based on the results of many trials performed on EuroFEX. Both the shoe-element and the heated counter roll have been redesigned and the new designs installed on EuroFEX. Further trials on EuroFEX with new design high-temperature pressing units have shown that the new design resulted in more flexible and efficient operation.

Laboratory experiments indicate that the risk of delamination of the fibre web can be reduced if a thin metal band instead of a heated metal roll heats the web. The use of thin bands could also improve the total energy efficiency of high temperature pressing, and simplify the conversion of existing shoe presses to high temperature pressing units.

Keywords: wet pressing, impulse drying,, mathematical models, pilot plant trials

1 The Partnership

Acronym	**Name**
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FEUP	Universidade do Porto, Faculdade de Engenharia, Departemento de Engenharia Química (*contractor*) Visiting address: R. Dr Roberto Frias, s/n 4200-465 Porto - Portuga Postal address: R. Dr Roberto Frias, s/n 4200-465 Porto - Portugal Codex Portugal Contact: Professor Carlos A.V. Costa
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2 Objectives of the project

The manufacture of paper from pulp requires a large amount of energy and a major part of the energy consumption is connected with de-watering (i.e. the removal of water from the pulp) and consolidation. A number of high-temperature pressing processes have been envisaged which could make a major impact on the efficiency of de-watering and consolidation. The introduction of such processes in paper manufacturing is expected to result in major energy savings, more efficient use of raw materials and a considerable reduction in the capital costs of new paper machines. They will also make it possible to enhance the quality of the products and even to develop new products using chemical reactions such as cross-linking (e.g. as are utilised in medium-density fibreboard pressing).

The objective of the project was to generate the necessary scientific and technical knowledge required for the understanding of new, high-temperature pressing processes and for the proper design and operation of such processes.

3 Technical description

The objectives of the project have been achieved by a combination of theoretical analysis and experimental investigations. Experiments have been performed on both specially designed laboratory equipment and on an experimental pilot-scale paper machine (referred to as EuroFEX in this report) that has two shoe-press units and is capable of running at the high speeds of modern paper machines.

Laboratory experiments have provided information on material properties (i. e. permeability and rheology) of the web and felt. Knowledge of the material properties is extremely important for all studies connected with pressing. Other laboratory experiments have been conducted to study the problem of web “delamination” and to evaluate different ways of reducing the risk of its occurrence.

Extensive pilot-scale experiments conducted on EuroFEX have made it possible to improve the design of the impulse pressing units and pressing fabrics, and to determine the operating conditions suitable for high-temperature pressing.

A general model of conventional and high-temperature pressing (including impulse pressing) based on the theory of flow in deformable porous media. The model uses data on material properties obtained from laboratory experiments and has been calibrated and validated with the help of data from specially designed experiments on EuroFEX. The model can predict the temperature, moisture content, steam pressure and density profiles within and immediately after the press nip. Such predictions are very useful for the understanding of the complex mechanisms active in the press nip. The model can be a valuable tool in the design and operation of high-temperature pressing equipment.

The main contribution of each individual Partner was as follows:

EFPG	Permeability and flow in fibrous structures.
LTH	Heat transfer and energy efficiency.
FEUP	Densification of the fibre web and the influence of chemical additives.
KTH	Study of delamination
Albany	Developing and supplying press felts for high-temperature pressing
Valmet	Optimising the high-temperature pressing unit.
STFI (co-ordinator)	Developing and validating a general model of high-temperature pressing. Planning, conducting and analysis of trials on the EuroFEX pilot paper machine.

4 Results and discussion

4.1 Heat transfer and energy efficiency

The energy efficiency of high-temperature wet pressing has been determined on a pilot scale paper machine and the heat transfer process has been modelled. The main results are summarised in the following sections.

4.1.1 Energy efficiencies

The total energy efficiency was mainly dependent on the roll surface temperature, the in-going moisture ratio, the basis weight and the press load. The highest total energy efficiency was obtained with a roll surface temperature lower than 100°C, with an in-going moisture ratio higher than 1.35 kg H_2O/kg ds (which is believed to be connected to the WRV), a high press load and with a high basis weight. The reason for this is that the wet pressing mechanism is more dominant under these conditions. It should be noted that the total specific energy use (TSEU) by definition equals zero at wet pressing conditions, since water is removed without heat.

However, this impulse unit was more energy-efficient than a modern dryer section even at a high roll surface temperature (e.g. 300°C) if the in-going moisture ratio was higher than 1.35 kg H_2O/kg ds. It should be remembered that a high roll surface temperature means increased water removal.

A higher total efficiency can also be obtained if the heat losses determined in Part I of this work are minimised. For example, if the efficiency of the induction heaters were increased to 80% the TSEU could be lowered by as much as 12.5%.

Since a low in-going moisture ratio affected the energy efficiency negatively it is clear from an energy efficiency point of view, that the impulse unit should be used as a second or a third press nip, and not as a fourth press nip. However, for positioning the intended paper quality and its WRV should also be considered. However, the impulse unit would also be usable for other reasons than its energy efficiency and consequently be used as a fourth press nip.

4.1.2 Modelling heat transfer

A basic heat transfer model for hot pressing and impulse drying has been developed. The model is based on the unsteady heat transfer equation in one dimension for a non-compressible media. The simulation results were compared with data from a laboratory press and data from an experimental paper machine running at industrial conditions.

The model showed good agreement with experimental data from the laboratory press at 0.5 MPa for both 60 and 150 g/m^2 sheets. Comparing the simulations with data from higher pressures showed an increased deviation. This trend is due to the considerable compression of the paper sheet. The compression induces a convective flow and changes the thermal conductivity, which affects the heat transfer. The agreement between the model and data from experimental paper machine was not as good as for the laboratory press. The model was compared with data where the lowest peak pressure was 2.75 MPa, which was above the pressure level of 0.5 MPa, where the model corresponded well to the MTS-data. Consequently, the simulations will deviate more at high peak pressures, as no compression of the paper is included in the model.

The overall conclusion from this study is that a simple heat transfer model can be used to simulate the heat transfer when the applied pressure does not exceed 0.5 MPa. Higher pressures require a more rigorous model that involves the compression. It could also be concluded that treating a paper-sheet as a semi-infinite solid and make use of analytical solutions is valid only for basis weights above 110 g/m^2. A comparison between the laboratory press and the experimental paper machine was made and a good agreement in the total energy transfer could be seen. From this result, it is reasonable to conclude that a laboratory press can be used to simulate heat transfer in hot pressing and impulse drying with a high degree of accuracy.

A more advanced model for high-temperature pressing was also developed with the purpose to investigate the internal heat transfer mechanisms. Special attention was paid to the compressibility of the paper during pressing. The model is one-dimensional and based on solving the energy equation for a compressible media. The paper is treated as a two-phase medium of cellulose fibres and water where the cellulose and water constitutes a homogenous matrix. No structural aspects of the paper have been considered in the model.

Simulations were carried out at different operating conditions and basis weights. The model showed good agreement with experimental temperature profiles for 60 g/m^2 sheets, especially for high peak pressures. Simulation of an experiment with a peak pressure of 0.5 MPa showed a less good agreement. The predicted temperature profiles were curvy and a possible explanation could be that the signals describing the model parameters tend to be wobbly. Wobbly input signals will have a direct effect on the results from the model.

The model was also used for higher basis weights. Simulations with 150 g/m^2 sheets were carried out and examining the results, a less good ability to predict the temperature profiles was observed. A reasonable explanation could be that the non-uniform consolidation of the web is more distinct at higher basis weights. Hence, as the model assumes a uniform consolidation it is likely that a somewhat poorer agreement is to be expected.

It has been shown, in spite of all simplifications and limitations, that the model is able to describe the heat transfer mechanisms during the compression phase. It is possible to explain the propagation of the temperature profiles with convective and conductive heat transfer without phase change. The compressibility of the paper has also a major impact on the heat transfer since the compression decreases the distance which the heat is transported.

The models ability to predict the internal temperature profiles supports the theory that impulse drying is a process with enhanced wet pressing due to the increased web temperature followed by flashing of superheated water.

4.2 Measurement of permeability

Two sets of experimental equipment have been designed for measuring permeability under compressive strain. One is dedicated to measurements on wet fibre webs and the other to measurements on felts. The permeability tensors of fibre webs and felts have been determined for a range of strain levels relevant for wet pressing

A schematic view of both the permeameters, for paper and felt are presented below, with pictures taken from the equipment built during this project. The compression device (for both paper and felt) is composed mainly of a pneumatic jack *(PNEURIDE - 370 mm in diameter)*, which is used to apply the stress on samples. Special equipment adapted on each cell keeps the device to be safe. This compression device allows an application of load of 10 tons, which leads to a stress of about 5 MPa on the studied sample.

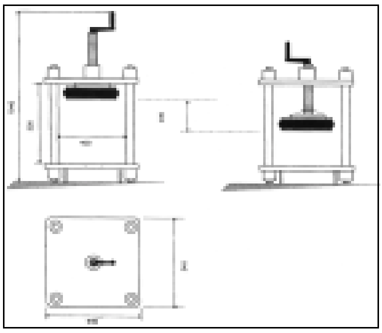


Figure 1: Schematic view of the compression device.

Felt permeability

The permeameter transversal device for felt imposes a flow perpendicular to the felt plane direction in order to measure the transverse permeability of the felt.

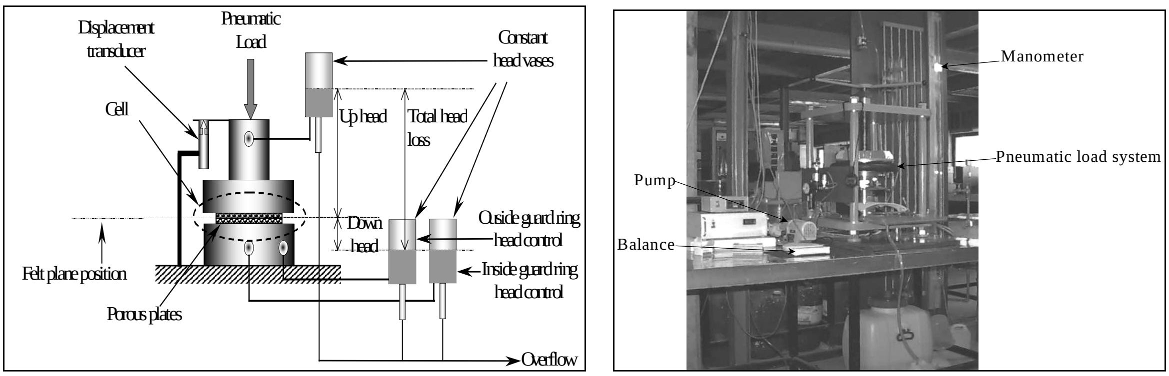


Figure 2 – Schematic description and picture of felt permeameter equipment

Permeability measurement process may be split into two parts: Firstly, the permeameter calibration consists in, measurement of compressed porous plates strain under loading, and measurement of flow and head loss of permeameter without felt sample. Secondly, measurements of both felt thickness and head loss of permeameter with a sample of saturated felt are realised. Permeability is then deduced from these results. Results are shown in the next section.

Web permeability

The main options retained and their justification concern the choice of the equipment and sensors that have to be introduced on the apparatus in order to allow correct measurement (see previous reports). Example of experimental results for paper permeability measurement is presented bellow. The obtained database is presented in the deliverable report.

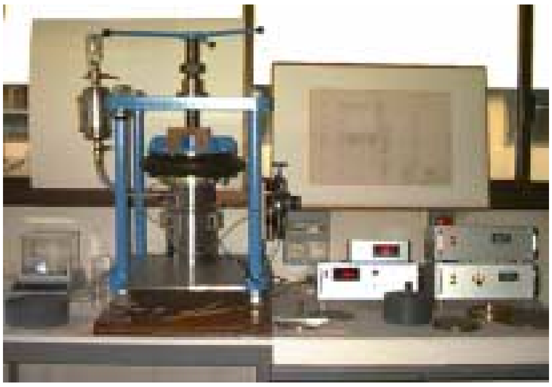


Figure 3 – Schematic description and picture of web permeameter equipment

Extensive tests have been carried out in order to establish a database that the other partners may use. We present below some examples of the obtained results for both fibre webs and felts. - Paper permeability

Web permeability

Sample	SR	Arrangement
15A	5	1 sheet
15Abis	5	1 sheet
15B	5	1 sheet
15C	5	2 sheets
28A	8	1 sheet
28Abis	8	1 sheet
28Ater	8	1 sheet and de-aerated water

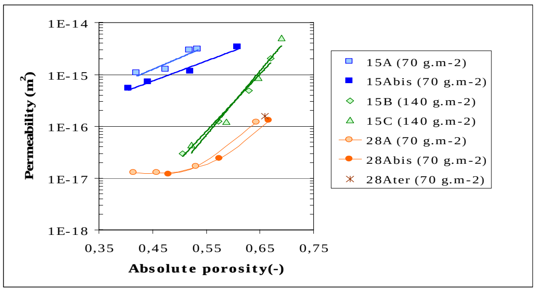


Figure 4: Results obtained for different hand sheets with the paper permeameter.

Permeability is expressed according to absolute porosity as required by our partner

Felt permeability.

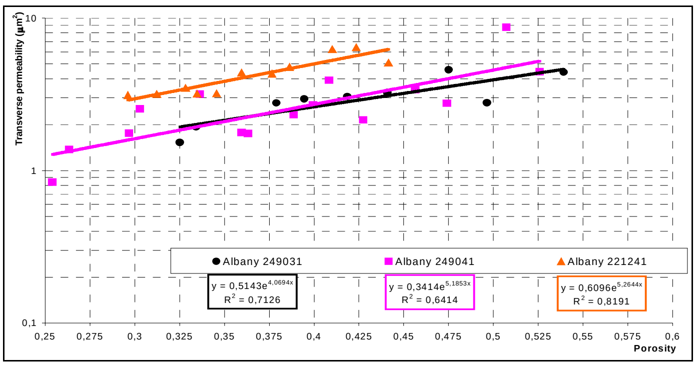


Figure 5: Results obtained for different hand sheets with the paper permeameter.

4.3 Densification of the fibre web

The densification of fibre webs during high-temperature wet pressing has been studied experimentally with the help of specially designed laboratory equipment.

Macklem and Pulkowski (1998) determined that the mechanism of impulse drying was a pressing/flashing-drying phenomenon. They suggested that the energy used to vaporise and heat up the paper web was equal to the heat transferred to the paper web, which suggests that the process is hot pressing combined with flashing of superheated water.

These same conclusions can be drawn, by observing the following figures. Pressure distribution in the nip from a pressing experiment is demonstrated in *Figure 6*. Here, a paper made from bleached *Eucalyptus globulus* was pressed in a 33 ms nip under a dynamic load up to 5.2 MPa.

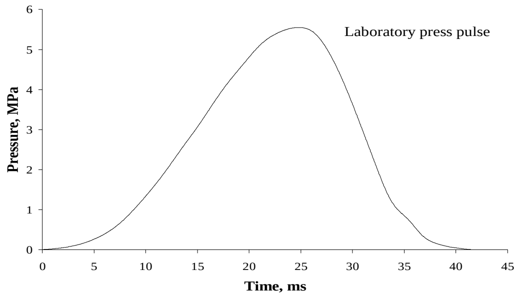


Figure 6. Standard, single-felted press pulse.

Figure 7 shows the pressure profile applied to a 60 g.m^{-2} 25 º SR wet paper sample plus felt. A significant decrease of thickness is observed at the very beginning of the pulse, followed by a gradual compression of the sandwich paper/felt, and finally a very fast recovery when the load is removed. All the paper grades studied in this work presented a similar behaviour in what concerns thickness variation, when subjected to the same pressure profile.

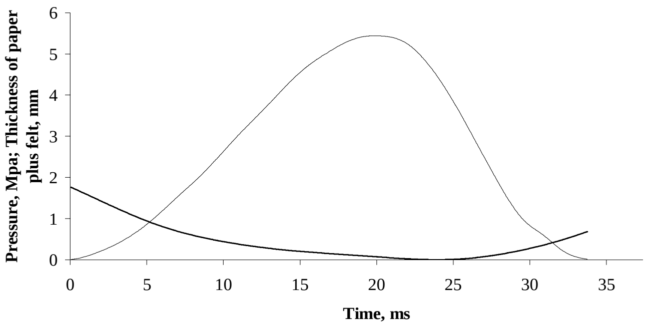


Figure 7. Thickness of paper plus felt at a peak pressure of 30.6 kN (5.4 MPa).

The increase in dryness experienced by the different grades of fibre webs during high-temperature pressing was measured. The nip residence time in these experiments was about 35 ms. Here dryness is defined as the percentage of dry mass of fibres to the total humid mass. The gain in dryness is defined as the ratio of dryness increase and the in-going dryness of the sheet.

A continuous increase of gain in dryness was observed with increasing pressing temperature. There is almost no dependence of de-watering rate on the refining level or basis weight. The water removal rate depends mainly on the pressing plate surface temperature, the press load and the in-going dryness. In conclusion, the most important aspect to note is that paper webs made of softwood pulps are more affected by the delamination phenomena and it can mask in some extent the experimental results.

A result of utmost importance was the achievement of a significant increase of dryness of the fibre web coming out of the pressing unit working at these higher temperatures and at a level pressure in the range of 5-6 MPa.

Webs of Eucalyptus globulus

The thickness for all paper sheets decreases with increasing impulse drying temperature. This decrease is more significant for the sheets with the lower refining level (25 °SR) and lower basis weight (60g/m^2).

Impulse drying can provide surfaces with higher smoothness at a moderate pulp refining level, which leads to a better printability. Unfortunately, for paper samples having higher basis weight and for highly refined pulps, the delamination on paper surface is a reality. It is proposed that lower refining degrees and basis weights should be used in order to obtain the best performance of impulse drying technique as for instance in the case of news-prints papers.

Impulse drying increases the web density of pulps made from bleached Eucalyptus globulus. Most paper strength properties are directly related to the sheet density, so higher strengths are also achieved such as tensile, burst, internal cohesion and tear. However, it was observed that properties such as stiffness and opacity decreased.

Finally, it should be said that pressing temperatures of 350 ºC must be avoided due to the negative effect verified on brightness and yellow index.

From the experimental study of paper containing additives it was found that impulse drying affects positively almost every mechanical properties. On the other hand, some optical and structural properties are negatively affected when very high-temperatures are imposed.

Pinus pinaster

In general terms, the effect of high-temperature pressing on paper made from Pinus pinaster is not so positive as we expected. Some mechanical properties are not improved by the impulse drying, namely stiffness and tear index, tensile index and internal cohesion are also affected negatively in some cases. However, Young's modulus and burst index were enhanced.

From a comparison between Eucalyptus globulus and Pinus pinaster, it was concluded that impulse drying is more beneficial for paper made from the hardwood pulp namely Eucalyptus globulus pulp.

Chemical additives

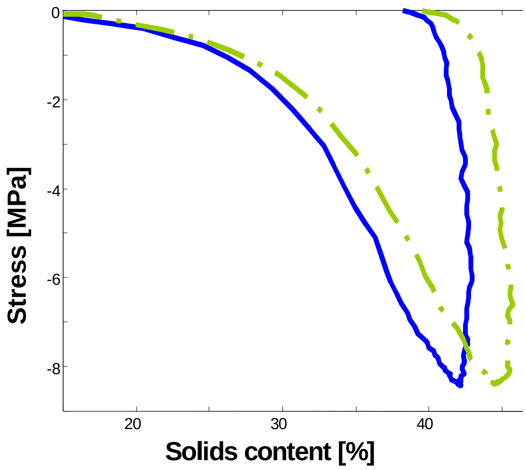
From the results achieved, it is possible to conclude that when small quantities of each additive are used their contribution to the elastic modulus of the paper is negligible. In some cases, despite the presence of high amount of additive in the pulp, the elastic modulus remained unchanged.

As for the case of urea-formaldehyde resin a first order kinetics was found for the cure reaction, although it turns into a zero order kinetic after 7 minutes approximately. The activation energy for the cure reaction was found to be near 35 kJ/mol.

4.4 A rheological model of wet fibre webs

A rheological model of wet fibre webs has been developed and its predictive capability evaluated with the help of extensive uniaxial compression tests. In each case, the applied pressure pulse recorded in the experiment was used as input to the model. The total strain was calculated and expressed in terms of solids content and the predicted stress-solids content relation was compared with the experimental result.

Tests with identical pressure pulses do not always give identical results, as may be seen in Fig. 8, which shows two experimentally determined stress-solids content curves obtained by the application of identical pulses. Such variations are not unusual and can be due to variations in grams between the samples. Samples from the same sheet can differ in grams by 2.5%. The age of the sample may also have an influence on the web compression behaviour, as the quantity of intra-fibre water (i.e. the water inside the fibre walls) may vary with time.



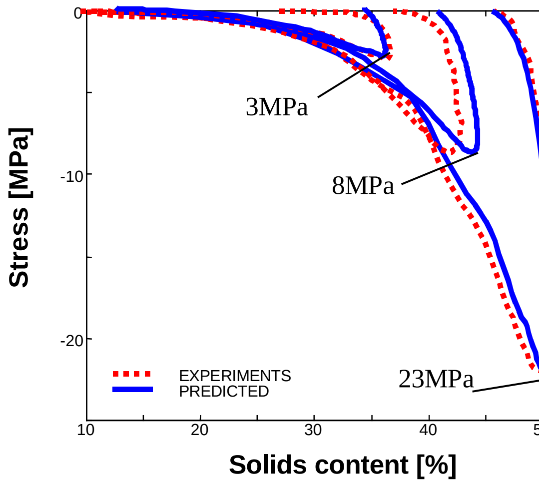
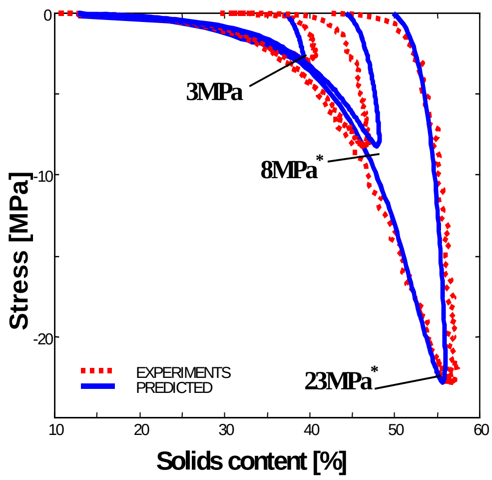


Figure 8: Two experimentally determined stress-modified strain curves obtained from tests with identical applied pulses (8 MPa and 75 ms). The difference between the curves exemplifies the order of magnitude of the experimental error. The tests were performed by Vomhoff.

Figure 9: The fit between test results for 25 ms roll-press type pulses with maximal peak pressures of 3, 8 and 23 MPa, and model calculations (using the estimated parameter values) for TMP webs. The tests were performed by Vomhoff.

The difference between the two experimentally determined stress peaks in Fig .8 (obtained from identical pressure pulses) represents a difference in solids content of 2.6%. This may be compared with the discrepancy between the experimental and predicted values at the peak stress in Figure (8MPa peak pressure pulse), which was about 2.5% solids content. The discrepancies between the experimental and predicted curves are of the same order of magnitude as the observed experimental scatter.



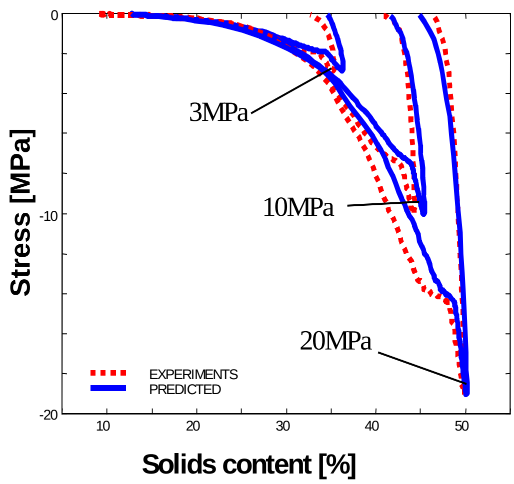


Figure 10: Comparison between test results for 2500 ms roll-press type pulses with max peak pressures of 3, 8 and 23* MPa and model predictions for TMP webs. The tests marked with the symbol * were performed by Vomhoff.*

Figure 11: Comparison between test results for 27 ms shoe-press type pulses with max peak pressures of 3, 10 and 20 MPa and model predictions for TMP webs.

The predictive capability of the model is shown in Figs. 10 and 11 for webs made of TMP and in Figs. 12 and 13 for webs made of SBK. The model predictions agree fairly well with the experimental results. There are, however, some discrepancies that may be partly due to experimental error.

Fig. 11 shows how the model predictions compare with test results using shoe-press pulses for TMP webs. Again, the agreement between the experimental results and model predictions was fairly good. This is a very interesting result because it shows that, in principle, the parameters need to be estimated only once and this can be done with almost any pulse shape. Predictions can then be made for widely different pulse shapes using the same set of parameter values.

Fig. 12 presents predicted and experimental stress-solids content relations for two different degrees of swelling of webs made of SBK. In both cases, the pressure pulse was 200 ms in length and reached 8 MPa in peak pressure. The agreement between predicted and experimental results was good.

Fig. 13 shows predicted and experimental results for two in-going web temperatures with pressure pulses of 20 and 2000 ms length and 10 MPa peak pressure for SBK webs. The agreement is good during loading part, but is not satisfactory in the unloading part of long pulses. Fortunately, such long unloading periods are not realistic in wet pressing. The proposed elastic/viscoplastic model can therefore be used to predict the fibre network stress of wet fibre webs of different furnishes, even when they are pressed at higher than ambient temperatures.

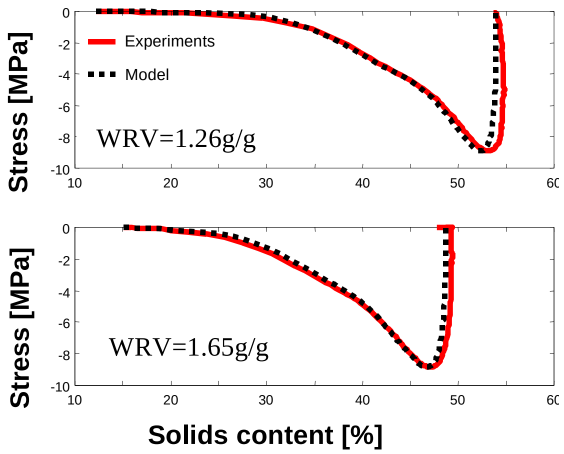


Figure 12: Experimental and predicted results for two different degrees of fibre swelling of SBK. The tests were performed with pulse lengths of 200 ms. The hydraulic pressure in the extra-fibre space for the case with WRV=1.65 g/g was not estimated and may be significant.

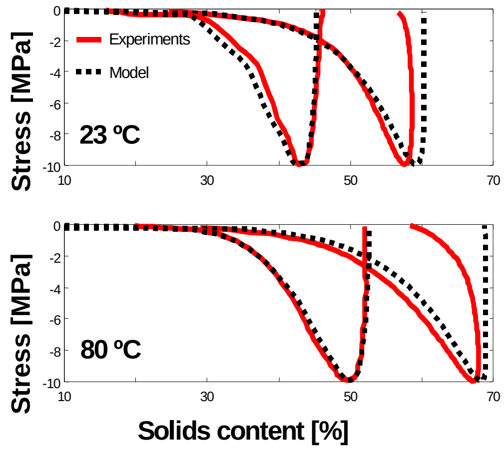


Figure 13: Experimental and predicted results for two different in-going web temperatures of SBK. The tests were performed with pulse lengths of 20 and 2000 ms.

4.5 Felt rheology

In connection with the development of felts for high-temperature pressing on EuroFEX, physical properties of felts were measured. Of particular interest were compression properties, shown in Fig. 14.

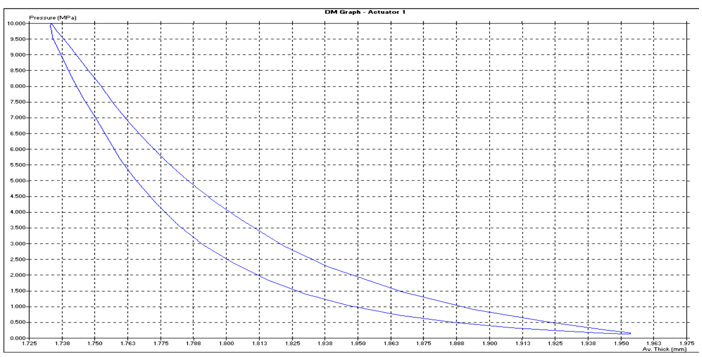


Figure 14: A typical stress- strain curve for felts used in high-temperature pressing trials on EuroFEX.

4.6 Dewatering Efficiency

In all the EurFEX trials, an increase in the temperature of the heated roll led, as expected, to a more efficient dewatering rate of the paper web, in agreement with the result of other researchers. Fig. 15 is an example of the results obtained in one of the first trials. In this case, bleached Kraft pulp was used and the machine speed was kept at 600 m/min. Only one impulse unit was used and the line load in that unit was 400, 600 or 800 kN/m. The maximum solids content after the impulse unit was almost 65 % and this was obtained at a roll temperature of 350 ºC. The increase in solids content compared to the value obtained without any heating, 44 %, is quite drastic.

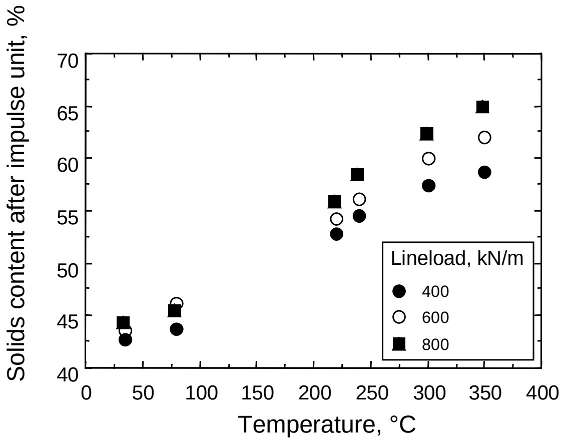


Figure 15: The solids content after the impulse unit as a function of the roll temperature and line load. Bleached Kraft pulp was used and the machine speed was kept at 600 m/min. The grams of the paper were 60 g/m². The solids content of the web going into the nip was approximately 40 %.

4.7 A general model of high-temperature pressing

A general model of high-temperature pressing has been developed and its predictive capability evaluated. *Fig. 16* present comparisons of the measured and predicted solids content after the third press for pressing at ambient temperatures. The model appears to give good predictions over a wide range of grams, machine speeds and loads. It may be noted that the shape of the pressure pulse varies considerably in the range of operating cases covered in this study.

There are, however, significant discrepancies between measured and predicted values that may be due to experimental errors or prediction errors. Experimental errors may be due to errors in the measurement of solids content (before and after the third press) and/or to the variability of the process.

Some indication of the size of the experimental errors may be obtained by studying Table 2. Compare the web solids content after the third press for the three cases in each trial that have identical operating conditions (with linear load 600 kN/m). The values of the solids content for the same operating condition can differ by up to 0.5 %-units.

We have tried to analyse the most significant sources of prediction error. Prediction error may be caused by error in the input data and/or by deficiencies in the model itself.

The effects of errors in the input data have been estimated by a sensitivity analysis, sensitivity being defined as the relative change in the solids content divided by the relative change in the parameter, for a small positive change. *Table 3* presents the sensitivity of predicted solids content (after the third press) to changes in those input parameters, which the analysis has shown to be the most significant.

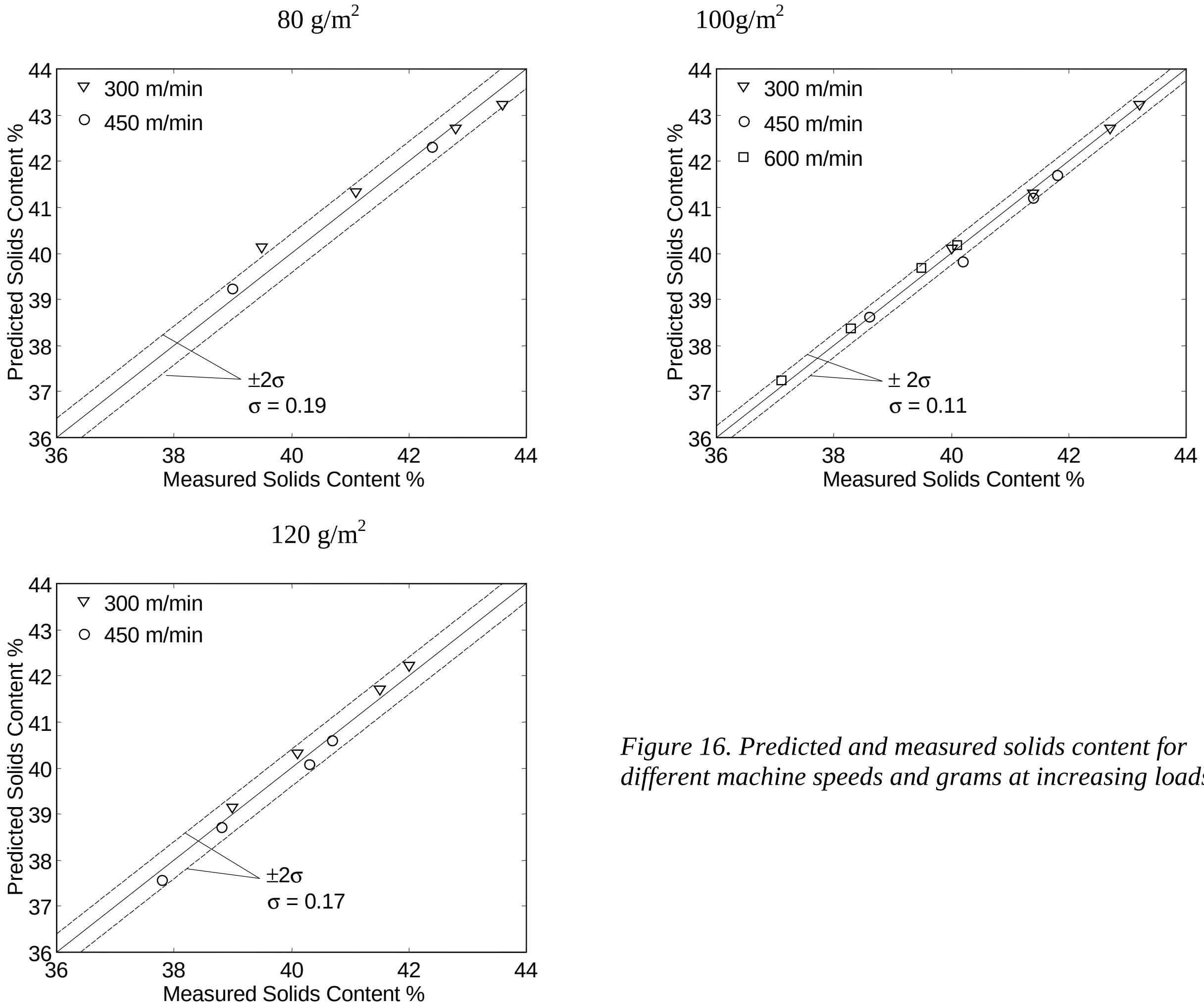


Figure 16. Predicted and measured solids content for different machine speeds and grams at increasing loads.

Table 3. *The sensitivity of the web solids-content after the third press to some important parameters (trial 4, load 1000 kN/m). Sensitivity is here defined as the relative change in solids content divided by a small positive relative change in the parameter.*

Solids content before the third nip	0.12
Water saturation	0.43
Parameter in the elastic equation (*k*)	0.17
Permeability equation exponent (*a*)	0.11
Density of cellulose	0.07
Fraction of bound intra-fibre water	0.06
Linear load	0.06

The model is most sensitive to errors in the measurement of solids content before the third nip. An analysis of continuous on line measurements indicates that the standard deviation of the in going solids content from the off line laboratory measurements is about 0.1-0.2 percentage points. Thus, measurement errors can explain most of the discrepancies between measured and observed solids content after the third press, as indicated in *Fig. 16* by the dashed lines. Since only two of the points in *Fig. 16* lie outside the 2σ-lines, we feel that the overall prediction capability of the model as regards solids content, is quite adequate for most engineering applications.

The effects of simplifying assumptions like the assumption of zero cross-machine direction flow and deformation, and discretisation errors have been shown to be negligible as compared to the experimental error.

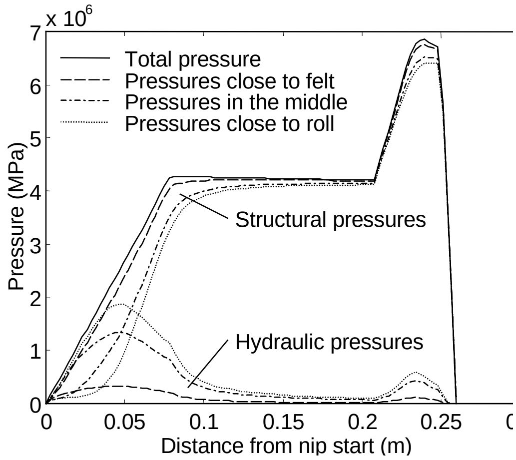


Figure 17. Calculated pressures along the third press nip of EuroFEX, at different levels in the wet fibre web.

This model can give interesting information about the sequence of events in the nip. *Fig. 17* shows how the local hydraulic and structural pressures (at different positions in web) vary inside the nip. Similar information can be obtained for a large number of local variables such as density, fluid velocity, permeability and saturation.

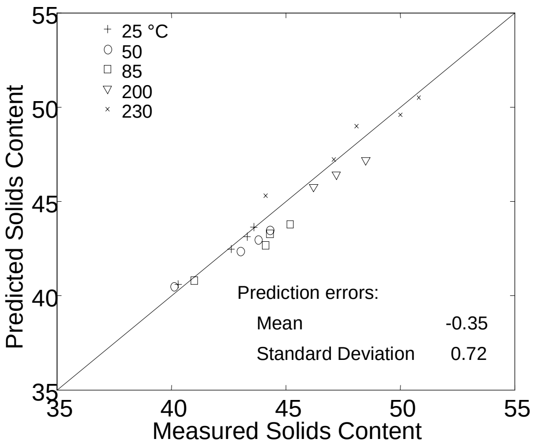


Figure 18. Predicted and measured solids content for different roll temperatures at increasing loads for grams 80 g/m^2.

The comparison between predicted and measured solids content for different roll temperatures and linear loads is shown in *Fig. 18.* The agreement is satisfactory but the standard deviation of the discrepancies in *Fig. 18* is clearly greater than that for the discrepancies in *Fig. 16*. Further, there are some systematic discrepancies in *Fig. 18* that should be noted. For low temperatures, when there is no evaporation, the model under-predicts the solids content. For high-temperatures, when there is evaporation, the model has a tendency to under-predict the increase in solids content with increasing linear loads.

Since the model gives good predictions when the press roll is kept at ambient temperature (*Fig. 16*), we conclude that the larger discrepancies in *Fig. 18* are related to changes in the press roll temperature. We believe this can be due to two sources of error. The first source of error is due to the difficulties of obtaining a representative sample of the fibre web after the third press and accurately determining its solids content when the press roll temperature is high. At present we see no practical possibility of reducing this source of error.

Another possible contributory cause of the discrepancies in *Fig. 18* may be the hardening curve stiffness values used at high-temperatures. The values used are based on extrapolation from measurements at lower temperatures, because the experimental determination of hardening curves is extremely difficult at temperatures above 100ºC. We believe that it is possible to reduce this source of error and we are working towards that goal.

4.8 Reducing the risk of delamination by using thin heating bands

One main problem in impulse drying is paper delamination. This occurs when the hydraulic pressure in the press nip decreases at nip exit, and water with a temperature over 100°C will then partly flash to vapour. When the internal vapour volume becomes too high, the paper will locally delaminate. The main idea with this work was to increase delamination temperature by using a thin band to restrict the hot surface temperature, and thus also the paper temperatures, towards the end of the press nip.

The experiments were performed at an earlier developed laboratory shoe press, the KTH-Press, which was modified to allow impulse drying. The press nip is formed between a 42-mm long press shoe and a rotating roll. The press force acting on the shoe is generated by a pressurised air bag, and pneumatic cylinders accelerate the press roll. A sandwich consisting of a lubricated plastic support, a press felt, a paper sample, the metal band and, on top, an insulating dry blotter paper is then fed into the press nip in a batch mode. The blotter paper is used to reduce the heat loss to the roll.

Before a pressing event, the back end of the band is preheated in an electric oven, see Fig. 19. The heated part contacts the paper sample just prior to the nip. The paper and band are separated immediately after the nip, since the paper sample sticks to the felt at high band temperatures.

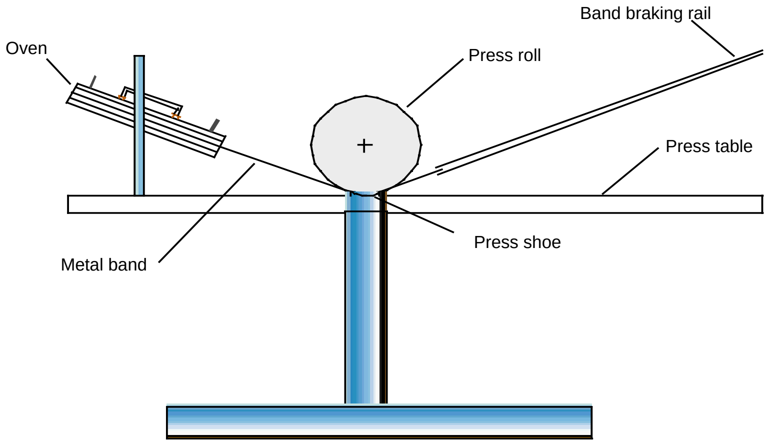


Figure 19. The KTH-Press modified for impulse drying.

Experiments to evaluate paper de-watering and delamination were performed with in-going band temperatures up to 450°C. Three different band materials were compared: Steel, copper and aluminium. Band thickness was chosen between 0.1 and 0.5 mm. The temperature events through the nip were recorded with a micro thermocouple, which followed the paper through the press nip.

The temperature events inside the paper web using 0.5 mm and 0.2 mm thick aluminium bands respectively, are shown in Fig. 20.

The slightly faster cooling of the paper surface using a 0.2 mm thick band caused, except for the felt surface level, a lower paper temperature compared with the 0.5 mm thick band. After the pressure release, vapour from the internal of the sheet may pass through the paper surface and decrease the surface temperature. The lower outgoing paper temperature will result in reduced vapour formation, a thin band could then be used with a higher initial band temperature while still avoiding delamination. The reduction in moisture ratio at the delamination temperature was slightly increased with decreased band thickness.

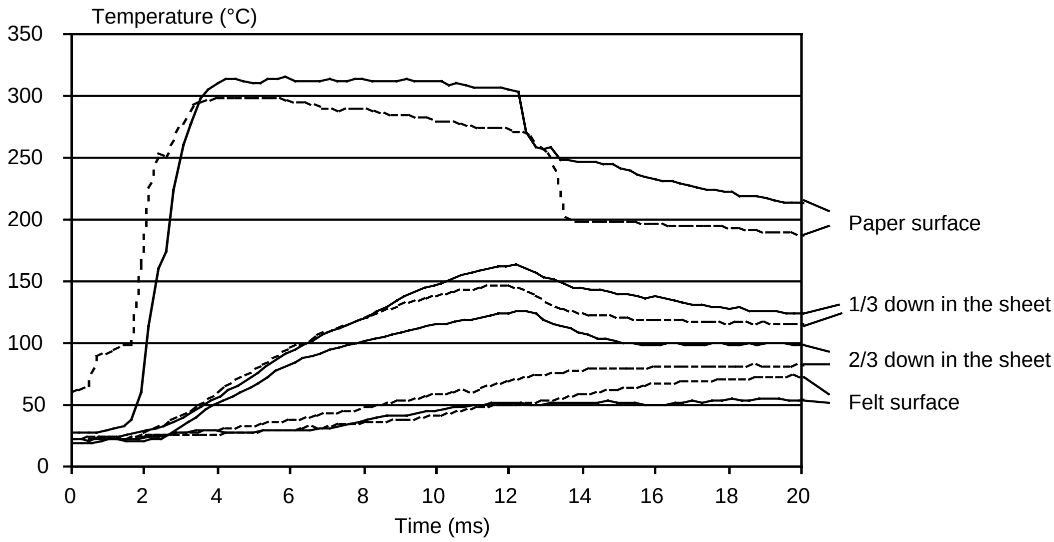


Figure 20. Temperature events in 60 g/m² sheet for 0.5 mm (full lines) and 0.2 mm (broken lines) thick aluminium bands, respectively. Initial band temperature 350°C. The load was applied approximately between 1 and 13 ms. Average nip pressure approximately 2.1 MPa. Sheets made of hardwood pulp, with in-going dryness 30-35%.

The main conclusion is that a thin heated band could increase de-watering without sheet delamination in comparison with a heated metal roll. The use of thin bands could also improve the total energy efficiency and simplify the conversion of existing shoe presses to high temperature pressing units.

4.9 New heated shoe press design gives more flexible and efficient operation

The original high-temperature pressing units on EuroFEX have been redesigned based on the results of many trials performed on EuroFEX. Both the shoe-element and the heated counter roll have been redesigned and the new designs installed on EuroFEX. Further trials on EuroFEX with new design high-temperature pressing units have shown that the new design resulted in:

- Greater flexibility in the operating conditions, i.e. both decreasing and increasing nip pressure, MD-profiles can be generated.
- A big improvements in shoe temperature control.
- Decreased heat-up time, i.e. the temperature of 300°C can now be reached in 1 hour instead of 8-12 hours needed earlier.
- Improved dimensional stability, i.e. the roll does not bend due to thermal gradients. Therefore even press load can be obtained in the cross direction of the nip.
- Possibility to use different kinds of roll covers.
- Excellent runs also under conventional press operation when no heating of the counter roll is performed

5 Exploitation plan and expected benefits

5.1 Exploitation plan

Those results that are of commercial interest will be exploited by the consortium Partners themselves. This policy is implicit in the Consortium Agreement that has been made between the Partners. Thus the consortium has no further obligation to pass its exploitable results to third parties.

Functional analysis

We expect the exploitable results from the project will be related to the design and operation of impulse pressing units and consider it appropriate that Valmet, a Partner who is one of the leading paper-machine manufacturers in the world, should be responsible for the exploitation of such results. Valmet has proved its competence in the introduction of new technology by the successful introduction of innovative products such as Condebelt drying and Impingement drying.

It should however be noted that the exploitable results of this project can at best only take us to the initial stage of the exploitation process; i.e. the pilot plant phase. The results of this project will be the basic scientific and technical knowledge required for demonstrating the technical feasibility of impulse pressing. We believe that at the end of this project there will still remain a considerable amount of work to be done in the pilot plant phase. This will include trials at high speeds and attempts to produce paper with new (and more desirable) combinations of qualities, which are made possible by impulse pressing.

Market study and Value analysis

A product analysis of impulse treated paper will be one of the first steps after the technical feasibility has been demonstrated. This will require large amounts of data from pilot plant trials. By comparing the properties of impulse treated paper with conventional paper, the relative strengths and weaknesses will be determined, and superior combinations can be found.

Exploitation strategy

The next step will be to identify the advantage of these combinations for a paper manufacturer in their specific situation. The introduction of impulse pressing will be a radical change in the paper making process with considerable risks involved. Therefore it cannot be expected that impulse technology will be applied directly in a new a completely new paper machine. The first ("demonstration") installation will more likely be part of a rebuild of an existing paper machine. The common motives for rebuilds are:

- Cost reduction
- Quality improvement
- Increased production capacity
- The advantages of impulse technology for the paper manufacturer should be shown in terms of the rebuild motive.

The potential for cost reductions can be examined for example in using less valuable raw material, less energy consumption or in using lower degree of beating of the pulp.

Based on the paper product analysis, the potential in quality increase can be figured out. The actual raw material on the mill, however, will have an effect on the results.

The high solids content after the impulse unit will promise a considerable production increase with the existing drying capacity. The existing constructions, however, may limit potential for speed and consequently production increase without other rebuilds along the production line.

Parallel to the process development a product (component) development phase will be necessary to develop a commercial impulse-pressing unit, based on the experience gained with the pilot-scale impulse pressing unit. The configuration of the impulse unit can however not be finalised until the whole process is acceptable, both process-wise and quality-wise. To get a customer involved is also important, because this is the only way to bring improvements to the process and the machine. In paper machine rebuilds generally, the application is made case by case because of various influencing factors. Therefore a single standard solution can not be given.

An important factor in bringing new technology to the market in the pulp and paper industry is the time scale. After the decision of the first installation it usually takes about a year to get it installed and in operation. After that the potential customers will evaluate the experience from the first reference and it will take a year or two before the decisions of second and subsequent installations are made.

Protection of results

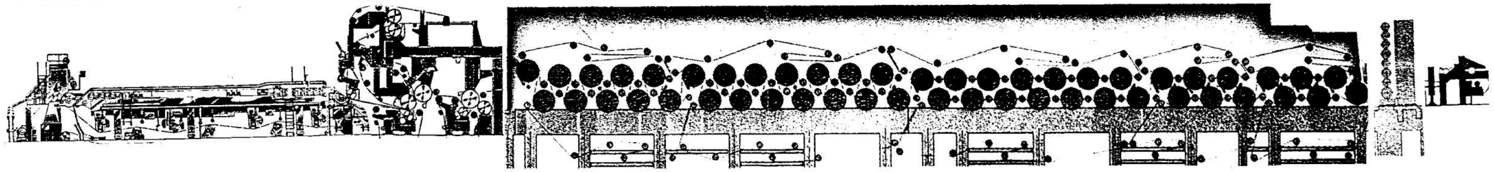
Valmet has received two patents based on project results, which may be of value in the design of commercial high-temperature pressing units.

5.2 Expected Benefits

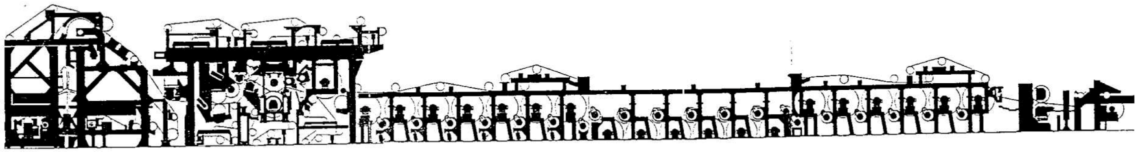
The introduction of high-temperature pressing in paper manufacturing is expected to result in energy savings, more efficient use of raw materials and a considerable reduction in the capital costs of new paper machines. They will also make it possible to enhance the quality of the products and even to develop new products using chemical reactions such as cross-linking.

When building new paper machines, the considerable reduction in capital costs that high-temperature pressing can result in (due to a much smaller dryer section), may well be a major consideration for paper manufacturers. This is illustrated by the figure in the following page.

Size of past paper machines



Present modern paper machines



New paper machines with high-temperature pressing