# Papridry™, A New Technique for Drying of Paper and Board

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## ABSTRACT

Drying is the least developed of all unit operations of paper and board manufacture. While groundbreaking developments were introduced during the several past decades in forming, pressing and calendering, no radical changes occurred in drying. The cylinder-drying technology is now more than 200 years old and, while it was subject to many incremental improvements, many of its inherent problems persist. We believe that conventional drying is now approaching the end of its life and the industry is ready for a major breakthrough in drying. Indeed several innovative technologies already exist at various stages of development or commercialization. In general, the novel drying technologies are striving to increase the drying rate, improve the product quality and boost the energy efficiency of drying. A novel, drying method, Papridry™, which combines conductive and convective heat transfer to obtain very high drying rates, is at an advanced stage of development at Paprican. The results obtained when drying printing paper and board on a self-standing pilot Papridry™ machine and on the pilot paper machine equipped with a tandem of two Papridry™ units demonstrate both, the high drying rate and improved product quality achieved by using this drying method. A mathematical model of this operation has been developed and the software compiled with this model was used to calculate the effect of installing a Papridry™ unit into an existing dryer section. The model also allows to calculate the z-direction distribution of moisture and temperature at various points of the dryer section.

## INTRODUCTION

After more than a century of incremental impro-vements, paper drying is still a slow operation, carried out-on the largest and most expensive section of the paper machine. The drying of printing and writing grade paper occurs as paper passes in a serpentine fashion around steam-heated cast iron drying cylinders usually arranged in two tiers (Figure 1). A good review of conventional drying can be found in references [1,2].

With as many as 60 or more rotating cylinders, the drying section is the longest and the most energy consuming part of the paper machine. The sheet is exposed to many open draws between the tiers, leaving it vulnerable to fluttering, damage and breaks. Sheet stretch in these open draws increases sheet porosity, impairs the Scott Bond strength and rougness, and drying may aggravate defects such as curl, cockling [3]. The open draws also allows the sheet to shrink in CD, particularly at the two edges. The lack of cross-machine direction (CD) restraint during drying results in non-uniform MD tensile properties and dimensional stability. Conventional cylinder drying does not provide any means for correcting sheet two-sidedness or generally improve the sheet quality.

The incremental improvements to cylinder drying, primarily driven by the desire to increase the machine speed, include dryer felts replacement by more permeable drying fabrics, pocket ventilation, web stabilization by blow boxes, and conversion of "double-felted" sections to "single-felted". The dryers of the fastest machines are now being designed as one long single-tier in which only one side of the sheet contacts the drying cylinders (Figure 2).

Single-tier dryers still do not restrain the sheet with respect to CD shrinkage and uneven drying of the two sheet sides might introduce sheet curl. Single-felted dryer sections have a similar number of steam-heated cylinders and evacuated, sheet-turning rolls and, consequently, are even longer than the double-felted dryers. Furthermore, the energy efficiency of conventional drying is low, as cylinder dryers typically consume 1.5 kg steam/kg of the water evaporated.

### Recent Developments in Drying

Alternative drying methods, using convective and radiative heat transfer, have been used for certain product types. For example, hot-air flotation dryers are commonly used for market pulp [5,6] and on a few machines for the initial drying of lightweight paper[7]. Tissue machines with Yankee cylinders (Figure 3) have traditionally used high velocity jets of hot gas impinging directly on the sheet.

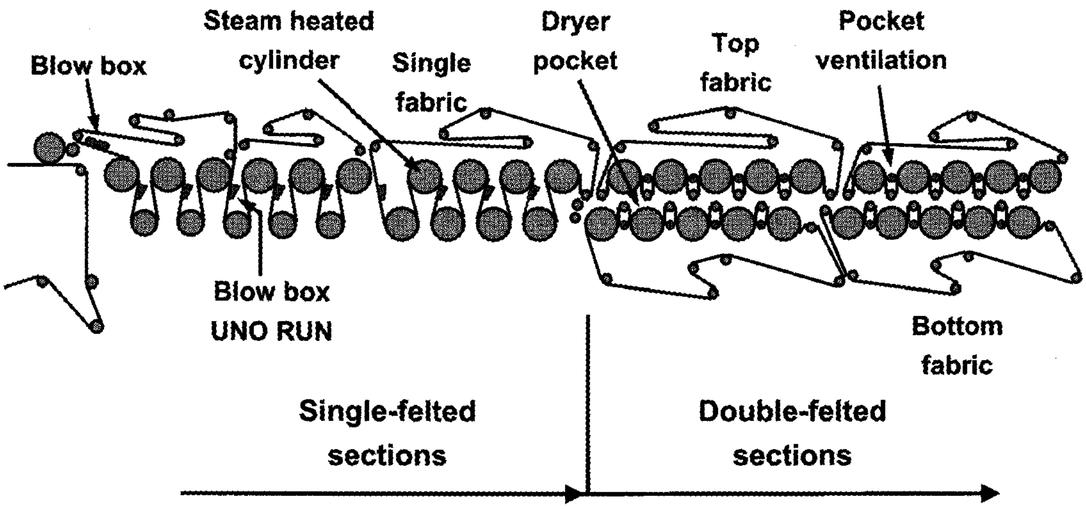



**Figure 1. Cylinder dryer with three single-felted and two double-felted sections.**

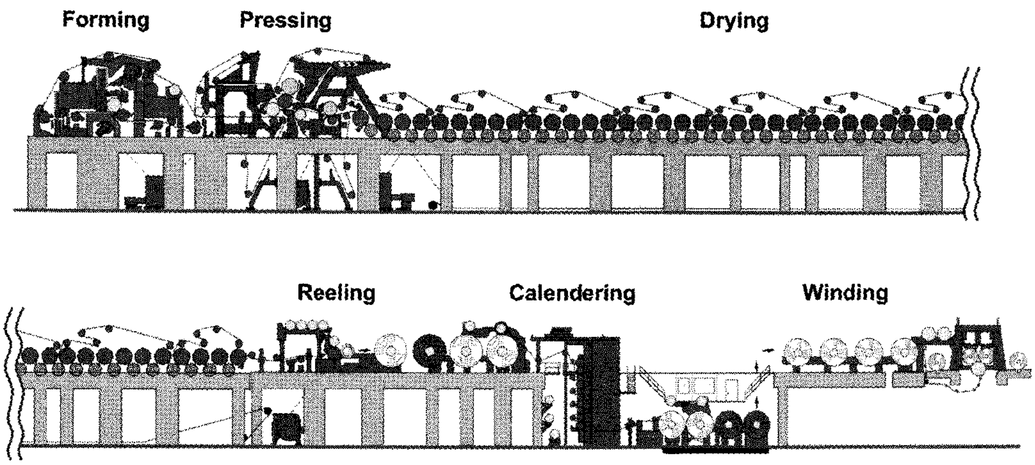



**Figure 2. The single-felted cylinder dryer of a recent Canadian paper machine [4].**

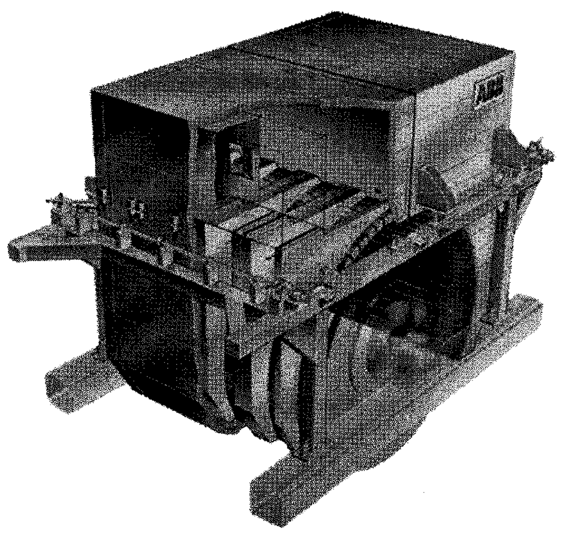


**Figure 3. Yankee dryer with an impingement hood.**

In through-air dryers, the impinging air actually passes right through the tissue. Convective or infrared drying, or some combination of both techniques is commonly used for initial drying of freshly-coated products. These drying methods are sometimes also used for moisture profiling of printing and writing grades. The high heat-transfer rate achievable by the impingement of hot air leads to high water evaporation rates, namely 200-500 $kg/m^2 \cdot h$ for tissue, dried either by high velocity impinging jets [8,9] or through-drying [10,11], compared to only 10-25 $kg/m^2.h$ for conventionally-dried printing and writing grades [12].

The OptiDry system, supplied by Metso, has been successfully operated on a commercial fine paper machine since 1999 [13]. In the first installation a large-diameter, evacuated cylinder, equipped with impingement hoods is located below the machine's operating floor [14,15]. The air heating and circulating equipment is located directly inside the hood, which eliminates the need for large ducts and blowers around the hood.

The drying rate can be enhanced by blowing hot air from a hood surrounding a conventional drying cylinder onto the wet paper sandwiched to the cylinder by the dryer fabric [16]. With this arrangement, the temperature and the velocity of hood-air were limited to protect the drying fabric, yet the impingement doubled the drying rate and allowed some curl control. This technique was developed by Beloit and it disappeared when Beloit ceased to exist.

An innovative drying technique the Condebelt dryer [17], was successfully commercialized by Metso [18, 19]. In the Condebelt process, the web is carried on two fabrics, one fine and one coarse, between two revolving steel bands (Figure 4). The top band is heated by steam and the bottom one is cooled by water. Water from the paper evaporates, passes through the fine fabric and condenses in the coarse fabric or on the cold steel band. The drying rates obtained on the commercial units are 5-10 times higher than those obtained in conventional cylinder dryers.

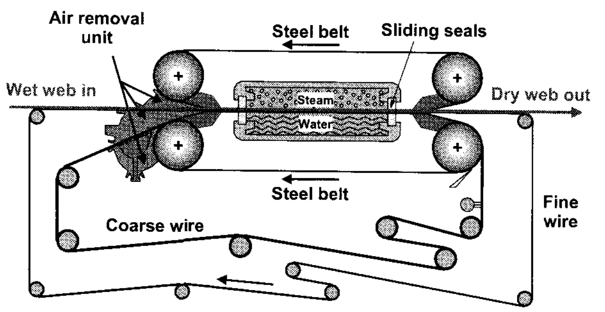



**Figure 4. Schematic of the Condebelt process.**

The first Condebelt dryer was installed in 1996 in Finland at Pankakoski [18] and in 1998, the second unit was installed at Dong Il Paper Mfg. Co. Ltd.'s Ansan mill in South Korea [19]. Condebelt drying increases the board strength properties and its resistance to humidity. The sheet surface in contact with the hot belt is very smooth and glossy but mottled. The side in contact with the fabric develops a pronounced fabric mark, but two-sidedness in roughness is not a problem for linerboard. Although the installation of a 22 m Condebelt dryer on a 1500 m/min newsprint machine was suggested [20], so far it has not been realized.

## THE PAPRIDRY™ CONCEPT

### The Concept

A new method for paper and board, Papridry™, has been developed at Paprican [21-25]. In Papridry™, wet paper is dried on two or more consecutive heated cylinders in such a manner that one side of the sheet is pressed onto the first cylinder and the other side is pressed onto the second cylinder (Figure 5). The web traveling on the cylinder is exposed to jets of hot gas blowing from hoods surrounding the drying cylinders. These hoods are similar to those used on a Yankee or through-dryer. Thus, Papridry™ employs known equipment in a novel way, which combines conduction and convection to achieve a very high rate of heat transfer.

The web leaving the last press with a solids content between 40% and 50% is pressed onto the first dryer by means of a felted suction press roll. Partially-dried web is removed from the first cylinder by a suction pickup press and pressed onto the surface of the second dryer cylinder by a felted or un-felted press roll. Upon pressing, the wet web adheres to the cylinder surface, which enhances the conductive heat transfer from cylinder and prevents shrinkage during drying. Sheet pressing onto the surface of hot cylinders resembles hot, soft calendering of wet sheets. Consequently the Papridry™-dried sheet is smoother, it requires less calendering than conventionally dried sheets. Depending on machine speed, basis weight and drying-cylinder size, additional drying capacity might be required for sheets leaving the second Papridry™ unit. Drying then might be completed by conventional drying cylinders or additional Papridry™ units.

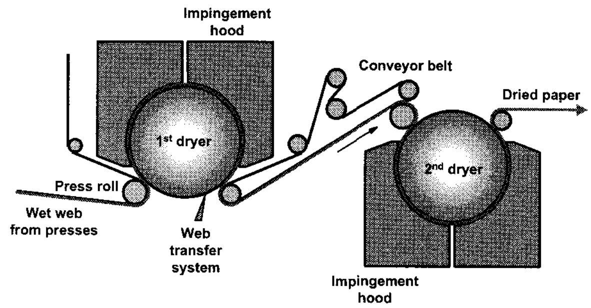



**Figure 5. Key features of a High Intensity Dryer [15].**

### A Self-Standing Pilot Papridry™ Unit

In order to confirm the potentials of the Papridry™ process and to assess its effect on paper properties, an off-line pilot scale unit was constructed at Paprican and used for the drying of several paper and board grades. The pilot dryer had a 1.5-meter diameter steam-heated cylinder equipped with a presser roll and surrounded by an impingement hood. The machine was equipped with an unwind stand, a reel, a pneumatic web tension control, and a computerised control and data collection system (Figure 6). The impingement air of this pilot unit was heated by an electric heater, which was less expensive and easier to operate than a gas or oil combustion system. Table I lists the principal design specifications of the system, and Table II lists the measured and controlled variables.

If this new technology becomes accepted, machines may be built in which all or almost all drying will occur on Papridry™ units. However, the installation of one or several Papridry™ units might be an excellent way to increase the drying capacity of an existing machine and also to improve the quality of its product.

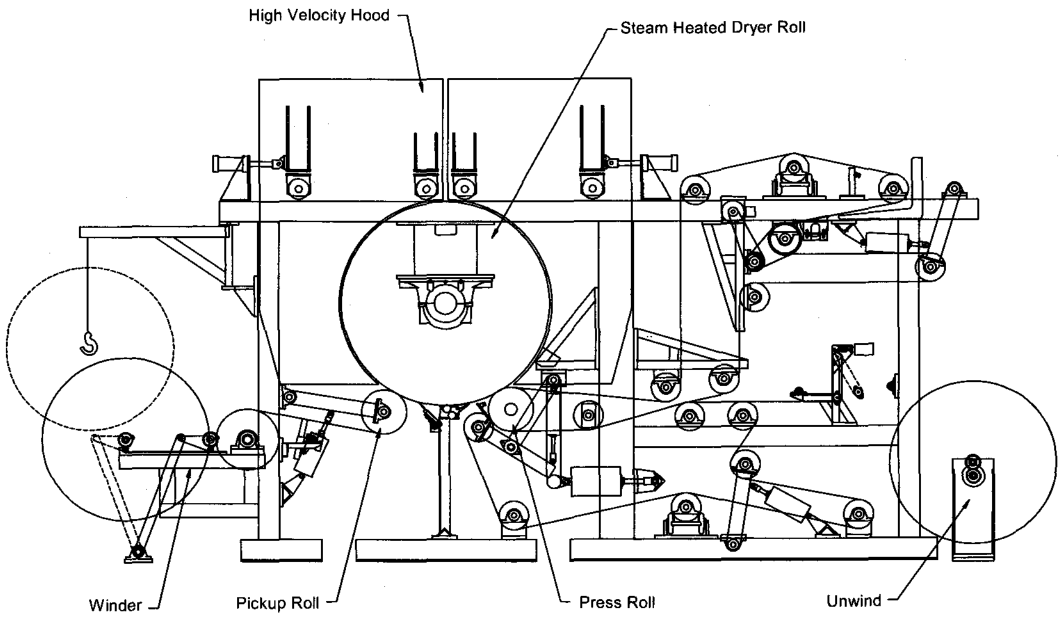



**Figure 6. Off-line single-cylinder Papridry™ unit.**

*TABLE I: Principal design parameters of the pilot Papridry™*

| | |
|---|---|
| *Drying cylinder diameter:* | *1.5 m* |
| *Cylinder heating:* | *Steam* |
| *Maximum speed:* | *300 m/min* |
| *Trim:* | *0.33 m* |
| *Unwind stand for wet paper:* | *Electric break and automatic web tension control* |
| *Impingement hood:* | *270° wrap around the cylinder* |
| *Impinging medium:* | *Air heated in an electrical heater* |
| *Press roll:* | *0.33 m diameter, rubber covered, hydraulically loaded* |

*TABLE II: Measured and controlled variables and the range of their values*

| | |
|---|---|
| *Machine speed (m/min):* | *70 – 250* |
| *Initial web solids content (%):* | *39 – 77* |
| *Pressure roll nip load (kN/m):* | *0 –140* |
| *Cylinder temperature (°C):* | *ambient – 140* |
| *Impingement gas temperature (°C):* | *ambient – 450* |
| *Impingement speed (m/s):* | *0 - 100* |

## Linerboard Trails using the Self-Standing Pilot Papridry™ Unit

We have used the self-standing pilot unit to measure the effect of Papridry™ on the drying rate and the properties of a 5-ply linerboard. The board had the basis weight of 205 $g/m^2$ and consisted of 2 white top plies and 3 brown bottom plies. The objective of this study was to assess the speed-up potential of an existing machine.

Dried and calendered board from a regular production was supplied by the collaborating mill. The board was rewetted on the unheated dryer by passing it at the speed of 10 to 30 m/min from the unwind stand to the reel while hot water was sprayed on the sheet before it entered the press nip. The rolls of rewetted board were wrapped in plastic foil and left to rotate slowly for at least 12 hours prior to being used in the drying experiment. The conditions required to obtain the target solids contents, 41%, 47% and 62%, were found by trial and error. These starting solids contents were selected to match three possible Papridry™ locations in the dryer section of the target machine, namely immediately after the existing press section, after the press section with a shoe press added, and in the position of an unused size press. The rewetted sheet was pressed onto the drying cylinder at the speed of 250 m/min, with a nip load of 50 or 100 kN/m, and ~330°C air was impinged onto the sheet at the speed of 95 m/s. The summary of operating conditions is in Table III.

The board samples were only partially dried on the pilot Papridry™ unit. Samples of partially-dried board were cut from the reel and drying of individual sheets was completed on a heated dryer designed for drying of Formette Dynamique sheets. Some rolls of the board, which were used for printing trials, were dried by passing them for a second time through the machine, which had both nips open.

The rewetting of commercially produced board is far from the ideal method of preparing samples for these drying tests, as it causes the loss of papermaking bonds. Therefore, as the control samples we selected rewetted and re-dried board, rather than the board received from the mill. Control 1 samples were rewetted and dried on the Formette Dynamique dryer, while Control 2 samples were rewetted passed through the unheated Papridry™ machine where they were pressed at 100 kN/m nip load, and then dried on the Formette Dynamique dryer.

*TABLE III: Operating Parameters of Pilot Papridry™ Unit*

| Run | Ingoing Solids (%) | Roll Temp. (°C) | Nip Load (kN/m) | Jet Temp. (°C) |
|---|---|---|---|---|
| 1 | 41 | 121 | 100 | 339 |
| 2 | 41 | 123 | 50 | 340 |
| 3 | 47 | 105 | 100 | 325 |
| 4 | 46 | 103 | 50 | 325 |
| 5 | 61 | 128 | 100 | 325 |
| 6 | 63 | 124 | 50 | 325 |

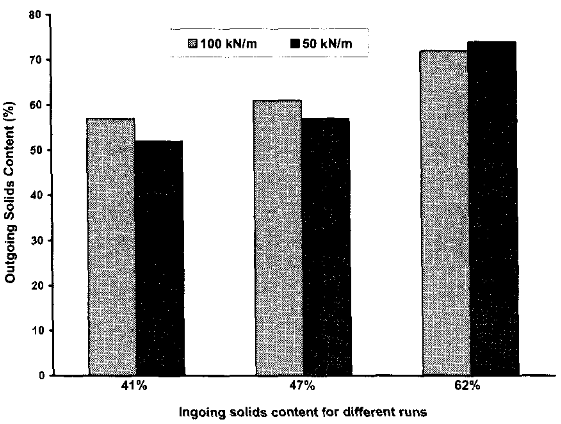



**Figure 7. Initial and final solids contents of Papridry™-treated linerboard.**

The initial and the final solids contents of Papridry™-treated samples are shown in Figure 7. It is remarkable that on a single pass through the dryer, the solids content of samples was increased from 41% to 57%, from 47% to about 60% and from 62% to about 73%. In Figure 8, the drying rates obtained in these experiments are compared with those of a typical conventional dryer section, namely about 25 $kg/m^2h$ [12]. The drying rates at an incoming solids content of 41% were close to 400 $kg/m^2h$. Although the rate of heat transfer declined with the increasing web solids content, the drying rate for partially-dried sheets with the initial solids content of 62% was still very high at 150 $kg/m^2h$.

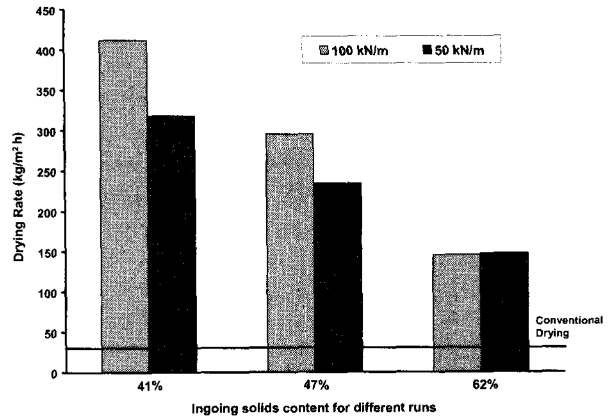



**Figure 8. The drying rate of Papridry™ is one order of magnitude greater than the average conventional drying rate of linerboard.**

A detailed description of board properties from these trials was presented in [24]. Papridry™-treated board had density increased by about 0.3 to 0.07 $g/cm^3$, which lead to a small increase in the tensile strength, modulus of elasticity and tensile energy absorption. The side ontacting the hot cylinder was smoother and required less calendering to reach the target smoothness. As it might be expected for a better densified sheet, the Papridry™ samples had greater Scott Bond strength and ring crush resistance [24]. The rolls of finished board were printed in the press room of the mills client. Figure 9 clearly indicates the Papridry™-treated board had a much improved print quality.

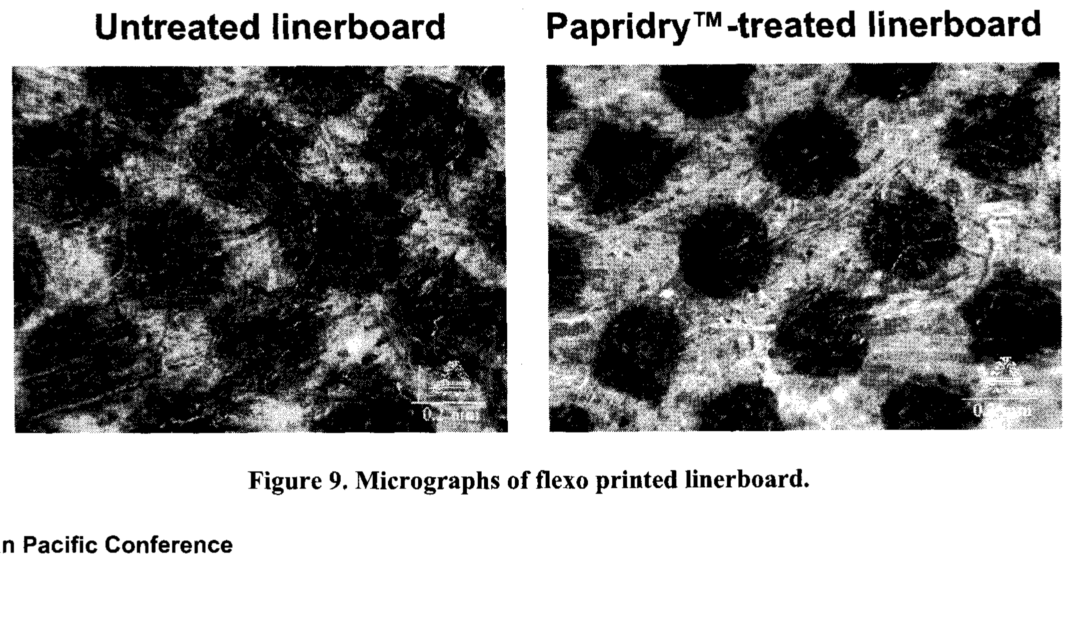



**Figure 9. Micrographs of flexo printed linerboard.**

### Printing Paper Trials Using the Self-Standing Pilot Papridry™ Unit

Papridry™ technology was originally designed for newsprint and other light-weight printing papers, for which the improvement in smoothness would result in improved print quality. We have used the self-standing pilot Papridry™ unit to dry mill produced mechanical pulp paper with a filler content close to 12%. Again, mill-produced paper was rewetted to the solids content of either 43% or 70%, which corresponded to the solids content after the last press or at the position of a size press of the paper machine in the collaborating mill. For this paper, which had the basis weight of 51.8 $g/m^2$, our Papridry™ unit had excessive capacity. With an impingement air temperature of approx. 340°C, the air velocity was kept down to 40 -50 m/sec to dry paper to the solids content of 93%. The drying rates required to reach this target dryness were 150 $kg/m^2.h$ and 60 $kg/m^2.h$ respectively for two incoming solids contents.

As for the linerboard described above, paper rewetting and re-drying had a negative impact on its strength properties. In these trials, we have not observed a significant change in the strength properties upon treating samples by Papridry™, but the rewetted and re-dried paper samples are not considered suitable for assessing the effect of drying on mechanical properties. When compared with the control samples, the Papridry™ samples had lower roughness and, therefore, required less calendering to reach the target Shefield roughness of 100 mL/min. Calendered Papridry™ paper had slightly higher gloss then the control samples.

The rolls of dry paper were sent for the evaluation of print quality to the R&D Center of Boise Cascade Corporation, where they were printed using the Didde Minicom Web Offset printing test. A portion of the image used for the evaluation of the print quality is shown in Figure 10. The print quality of Papridry™-treated paper was generally comparable to that of the control samples, but all Papridry™ samples had slightly higher print densities and more uniform solids with less mottle. Better ink laydown was also apparent.

The Pruefbau printing tests carried-out in our laboratory revealed that the Papridry™ samples had a slightly lower and more uniform show-through than the control samples. More specifically, the backside brightness for unprinted/printed Papridry™ samples was 70.0/65.5 for a loss of 4.5 points, while that of the control sample was 72.0/66.0 giving a brightness loss of 6 points.

From the print tests it can be concluded that, Papridry™ treated paper and board prepared as described in this report had a slightly better print quality than the comparable control paper. One might expect that product treated by Papridry™ directly on the paper machine would have an even better printing quality as it would not experience mechanical manipulation, which is known to increase sheet porosity and linting tendency.

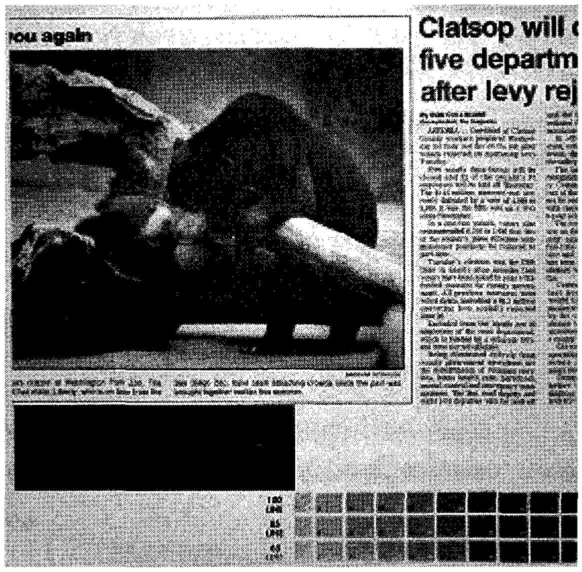



**Figure 10. The image used to evaluate the print quality of paper.**

### Newsprint Trials Using On-Line Papridry™ Units on a Pilot Paper Machine

Based on results obtained using the self-standing pilot unit, new, fast, pilot paper machine was built at Paprican with two on-line Papridry™ units. These dryers receive freshly-made paper, producing results comparable with those from a commercial installation. A general description of Paprican's pilot paper machine (Figure 11) including a rudimentary description of its dryer section has been published [26]. The machine was used for Papridry™ drying of several printing papers and some results obtained for newsprint are presented below.

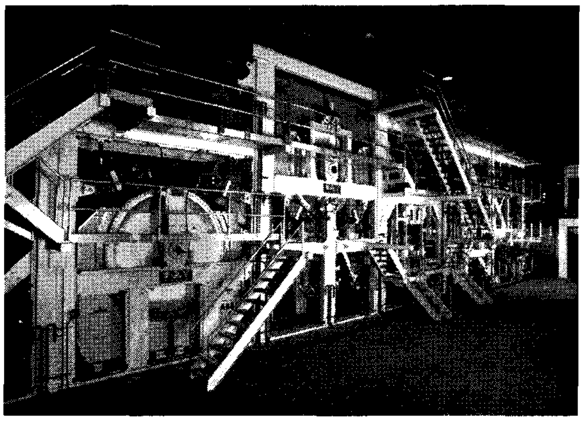


**Figure 11. Photo of the two Papridry™ units on Paprican's pilot paper machine**

Newsprint of 46 $g/m^2$ was produced in the twin former from 80% TMP and 20% DIP usually at 815 m/min. The wet web was compressed in the press section by three or four press nips to solids contents between 42% and 50%. The dryer section of Paprican's pilot paper machine is composed of two consecutive Papridry™ units, each consisting of a 3-m diameter steam-heated cylinder equipped with a high-velocity hood (Figure 12). The wet web was pressed onto the first drying cylinder at loads

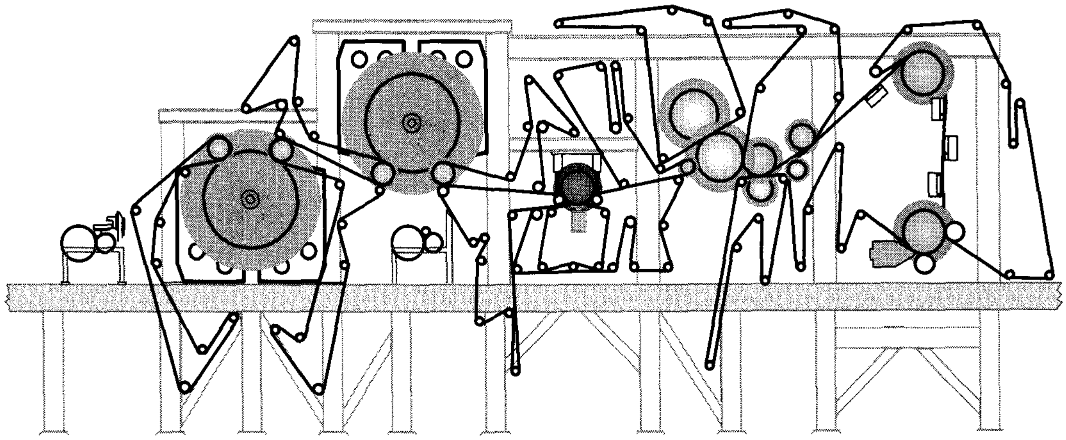


**Figure 12: Scheme of Paprican's pilot paper machine showing the web run.**

ranging from (20 kN/m) to (110 kN/m) and gas obtained by combustion of natural gas was blown onto paper at temperatures from 315°C to 575°C at a velocity ranging from 55 m/s to 125 m/s.

Impingement temperature and velocity of the first drying unit determined the incoming solids content of the second Papridry™ unit. The second Papridry™ unit is inverted, to allow the contact of the opposite web side with the hot cylinder, thus improving the smoothness of both sheet sides (Figure 12). The partially-dried web entered the second unit at the solids contents between 50% and 68% and was pres-sed onto the dryer cylinder with nip loads ranging from 50 kN/m to 120 kN/m. Drying air between 255°C and 455°C was impinged at a velocity ranging from 30 m/s to 125 m/s.

The adhesion of the sheet to the cylinder surface stabilized the sheet and prevented CD shrinkage as it traveled, un-felted, on the rotating, steam-heated dryer cylinder. The solids content after these two consecutive Papridry™ units varied from 60% to 85%. When drying conditions were pushed to the limit we were able to dry the 42 g/m$^2$ sheet completely. After the second HID unit, the partially or completely dried web is collected on the reel. In a majority of trials, paper samples collected from the reel were further dried while sandwiched between two blotters on a Dynamic sheet former dryer.

*Table IV: Operating conditions during pilot paper machine trials*

| | *Unit #1* | *Unit #2* |
|---|---|---|
| *Incoming solids content, %* | ***42-50*** | *50-68* |
| *Outgoing solids content, %* | ***50-68*** | *60-85* |
| *Dryer steam pressure, psig* | ***15-50*** | *15-50* |
| *Press nip load, kN/m* | ***20-110*** | *50-120* |
| *Impingement air temperature, °C* | ***315-575*** | *255-455* |
| ***Impingement air velocity, m/s*** | *55-125* | *30-125* |

Table IV shows the wide range of operating conditions explored during the experiments performed on Paprican's machine. The pressing conditions were varied to investigate the effect of solids content on drying rates and paper properties.

## Results Obtained with Two On-Line Papridry™ Units

Figure 13 summarizes more than 150 drying tests and shows the drying rates obtained for one Papridry™ dryer (the first or the second unit) as a function of the incoming sheet solids content. Evaporation rates obtained using a range of conditions defined in Table IV varied from 60 to 240 kg/h.m$^2$. These drying rates were one order of magnitude higher than those achieved in conventional cylinder drying (15-40 kg/h.m$^2$) [12]. These very high drying rates, obtained by a combination of efficient heat transfers from the cylinder and from the impinging hot air are similar to those reported for Yankee machines [27].

In our experiments, we did not operate at the full capacity of the system, because the drying rates were limited by machine runnability. When the drying rate exceeded certain critical values (see the black points in Figure 13) the sheet became detached from the cylinder surface by a very thin layer of impingement air and steam, a phenomenon known in tissue production called bubbling. Once the sheet is detached from the drying cylinder the heating by the cylinder is interrupted and, although the temperature of the dryer surface increases, the drying rate is reduced. Thus the dashed line in Figure 13 indicates the limit of drying rates suitable for a commercial application. Although bubbling limited the drying rate obtained by Papridry™, it was not a severe limitation, as the safe drying rates were still about ten times higher than those achieved in conventional drying.

Figure 13 indicates that if a Papridry™ unit is retrofitted into an existing dryer, its drying rate will depend on its location within the dryer section. At the wet-end of the dryer section, where the sheet solids content is between

40%-55%, drying rates are expected to range from 115 to 200 kg/h.m$^2$, while a unit located closer to the end of the dryer section, where the initial solids content is 55% – 75%, could operate with drying rates ranging from 60 to 115 kg/h.m$^2$.

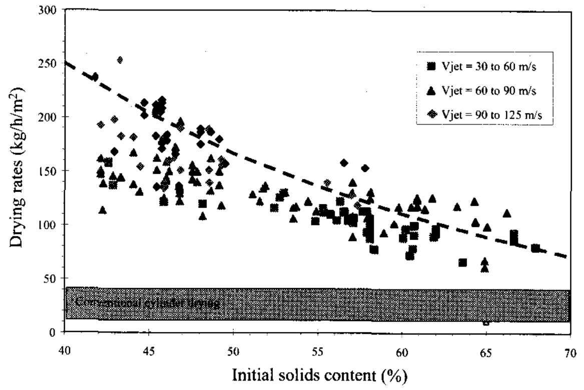



**Figure 13. Papridry$^{TM}$ drying rates of a 45 g newsprint sheet at various air-impingement velocities as a function of initial solids contents.**

Only limited information on the Papridry$^{TM}$-dried sheet properties are available at this time; additional information will be published later. The continuous, high speed operation confirmed the results obtained on the self-standing unit: The sheet denser, glossier and smoother than the conventionally dried sheet (Figure 14).

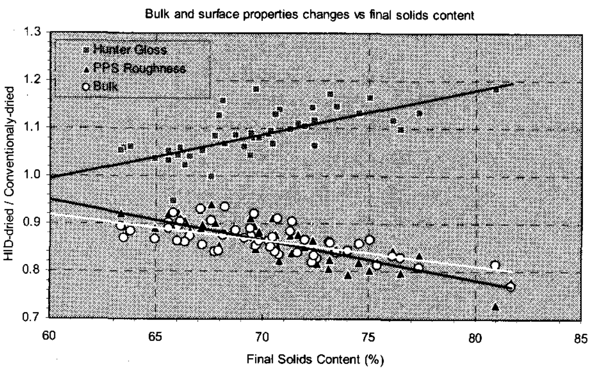



**Figure 14. The ratio of Papridry$^{TM}$- dried newsprint bulk, roughness and gloss to properties of conventionally dried paper.**

The drying trials with rewetted newsprint using a self-standing Papridry$^{TM}$ unit (see above) did not reveal a significant improvement in the mechanical properties of paper, as rewetting and the mechanical manipulation of wet-web reduced the sheet cohesion and offset the possible effect of Papridry$^{TM}$ drying. A test of paper produced on a pilot machine and dried on-line by Papridry$^{TM}$ revealed a significant improvement in the tensile strength (Figure 15). There was a corresponding increase in TEA and Scott Bond strength, but a reduction in tear strength. As the Papridry$^{TM}$ sheet was denser and smoother, less calendering was required to reach the specified roughness and, therefore, the sheet lost less strength during calendering.

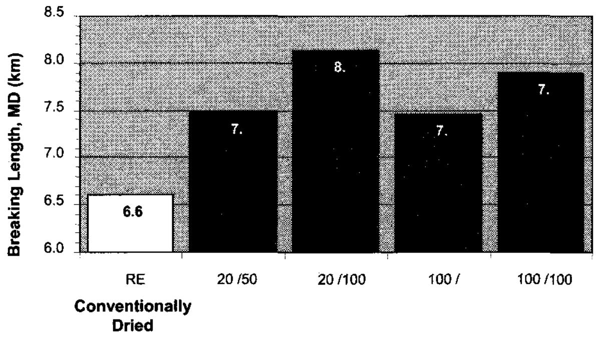



**Figure 15. Papridry$^{TM}$-dried sheet was stronger then the conventionally dried paper.**

One of the major and very common defects of newsprint is excessive propensity to deposit lint on the blanket of the printing press, which leads to poor print quality. A shut-down for blanket washing affects the production and leads to the waste of paper and ink. The initial reports on this technology indicated that sheet compression to a hot cylinder, followed immediately by drying, leads to improved fibre-to-fibre bonding and Scott Bond strength. Such an effect might help to lower the linting propensity. As shown in Figure 16, this assumption was confirmed. Newsprint that was partially dried by Papridry$^{TM}$ had drastically reduced linting propensity. The elimination of linting might be a powerful driving force for the commercialization of Papridry$^{TM}$.

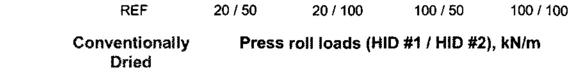
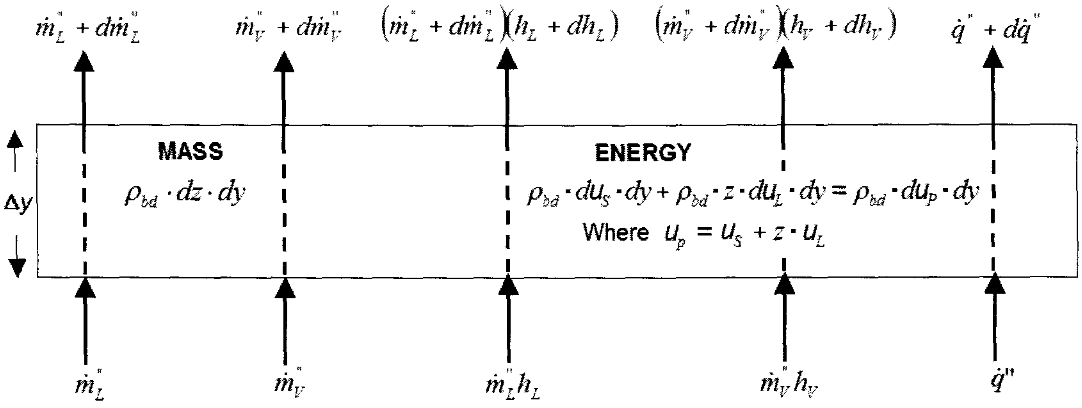



**Figure 16. The linting propensity of newsprint was drastically reduced by Papridry$^{TM}$ treatment.**

## Mathematical Modeling Papridry$^{TM}$ Operation

To facilitate the commercialization of this new technology, a mathematical model has been developed in collaboration between Paprican and IPST [28]. In particular, the model was designed to estimate the required number and size of Papridry$^{TM}$ units at various positions of the dryer section to reach the desirable drying capacity.

In the model, the paper web is considered as a superposition of several elementary plies of thickness $\Delta y$ where the numerical value of $\Delta y$ is chosen so that the




continuum approach for porous media applies. The following partial differential equations relate the changes in moisture, z, and temperature, T, over time, t, and were developed performing a mass and energy balance over an elementary ply. The finite volume method was applied to solve the coupled partial differential equations for each elementary ply.

$$\rho_{bd}\frac{\partial z}{\partial t} = -\frac{\partial}{\partial y}\left(\dot{m}''_L + \dot{m}''_V\right)$$

$$\rho_{bd}c_P\frac{\partial T}{\partial t} = -\frac{\partial}{\partial y}\left(\dot{q}'' + \dot{m}''_L h_L + \dot{m}''_V h_V\right) + u_L\frac{\partial}{\partial y}\left(\dot{m}''_L + \dot{m}''_V\right)$$

The model, described in details in [28], was validated and tuned based on results of experiments using Paprican's pilot paper machine. From the more than one hundred experiments performed at the pilot scale, an additional seven were selected for simulations. These experiments were chosen to cover a wide range of operating conditions. Figure 17 shows a good match of the predicted drying rates with the experimentally measured drying rates.

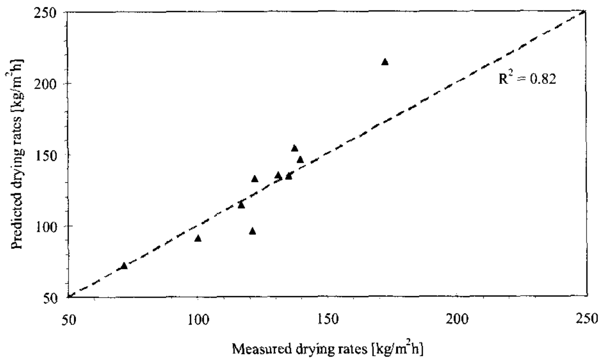



**Figure 17. Comparison of drying rate measured and predicted by the Papridry™ model [28].**

Figure 18 shows the temperature distribution in the sheet thickness during drying by Papridry™. By controlling the ration of water evaporation by the cylinder and by the hood, it is possible to control the temperature profile and the solids content distribution on two paper surfaces and thus influence the product's curl [29].

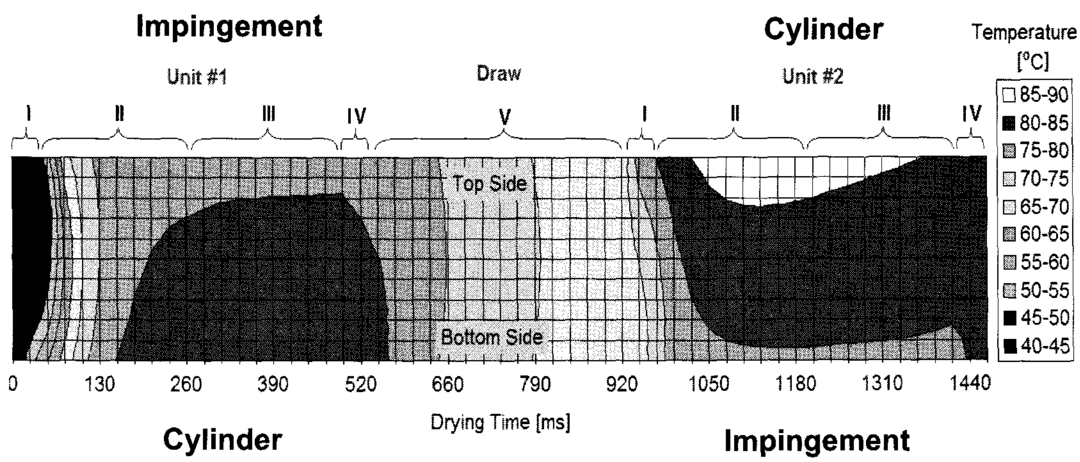



**Figure 18. The temperature profile in the sheet thickness during Papridry™ drying [30].**

## Papridry™ for Boosting Capacity of Paper and Board Machines

The capacity of an existing dryer section could be increased, without increasing its length, by replacing a limited number of conventional cylinders with one or several Papridry™ units. The increased drying capacity would increase the production or, alternatively, new equipment could be installed in the space of the dryer section, such as soft calender, size press or coater. A method has been developed to calculate the number and size of Papridry™ units to reach the desired drying capacity depending on their location within the existing dryer section. The method was applied for two Canadian machines, one producing newsprint, and the other linerboard [30]. The calculation is based on the realistic drying rates for these two grades, shown in Figure 19, which were determined by calculations and experiments.

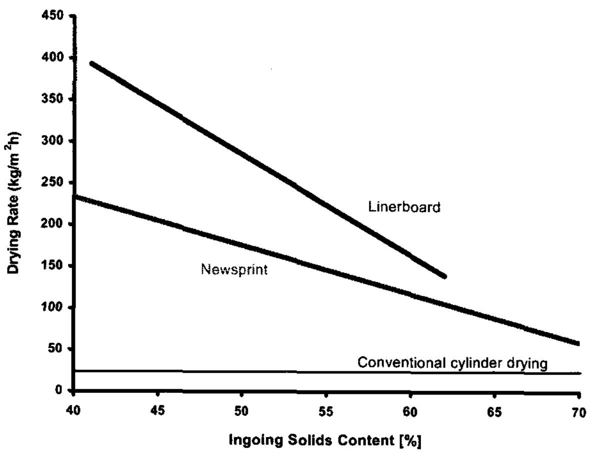



**Figure 19. Drying rates of Papridry™ for linerboard and newsprint compared with average drying rates of cylinder dryers.**

In the first step, a mathematical model of conventional dryer section was used to calculate the drying rate and the solids content for each drying cylinder. We have used the software "Vision" developed at Texas A&M University [31]. Using the date displayed in Figure 19, we then calculated the drying rate at, and the solids content after, the Papridry™ unit, which displaced a certain number of conventional drying cylinders. The remainder of the dryer section (cylinders after Papridry™) is treated as a new section with a known initial condition and a desired final solids content. This procedure is inherently iterative. A value for machine speed is assumed, then the final solids content is predicted and compared with the actual value, with the procedure repeated until an acceptable match is achieved. Since the new, higher machine speed also applies to the cylinders located before the Papridry™ unit, the sheet solids content entering and exiting the unit will decrease when machine speed increases. Therefore, all three steps have to be repeated, with the assumed speed, until an acceptable convergence is achieved.

The installation of a Papridry™ unit was simulated for a machine equipped with 46 drying cylinders, producing 48.4 g/m$^2$ newsprint at 1133 m/min. The installation of a unit with the cylinder diameter of 4 m was considered at the beginning of the dryer section, after the cylinders, 22 and 30. In each location, the Papridry™ unit takes the place of 6 existing cylinders. Simulation results, summarized in Table VI, demonstrate that the maximum speed-up potential of Papridry™ for this newsprint machine was 42%. The speed-up potential of Papridry™ decreases as it moves away from the press section. However, the last scenario simulated, where Papridry™ was installed after cylinder 30 and close to the end of the dryer section, would still provide a 13% increase in machine speed. This example demonstrates that the beginning of the dryer section is the preferred location for the installation of Papridry™ to obtain the highest increase in the drying capacity [30].

*TABLE VI: Summary of simulation results for the newsprint machine.*

| *Option No.* | *Location of Papridry™* | *New Machine Speed (m/min)* | *Speed Increase (%)* |
|---|---|---|---|
| *1* | *After the press section (cylinders 1 to 6 removed)* | *1610* | *42* |
| *2* | *After cylinder 5 (cylinders 6 to 11 removed)* | *1530* | *35* |
| *3* | *After cylinder 22 (cylinders 23 to 28 removed)* | *1330* | *17* |
| *4* | *After cylinder 30 (cylinders 31 to 36 removed)* | *1280* | *13* |

## CONCLUSION

Papridry™ is a promising alternative to convectional, multi-cylinder drying. By providing a drying rate an order of magnitude greater than the conventional dryer section, it offers the possibility of substantially reducing the size of paper machines and their capital costs. Perhaps a more important benefit provided by this new technology is improved product quality, in particular the print quality. The initial installations of Papridry™ will likely be retrofits of existing machines with the objectives of increasing the machine capacity and product quality. This report presents a feasible solution for increasing the drying capacity of an existing paper machine without extending the dryer section. The extra drying capacity would allow for a substantial increase in machine speed, or could be used to accommodate a size press, soft calender or other equipment required for upgrading product quality.

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