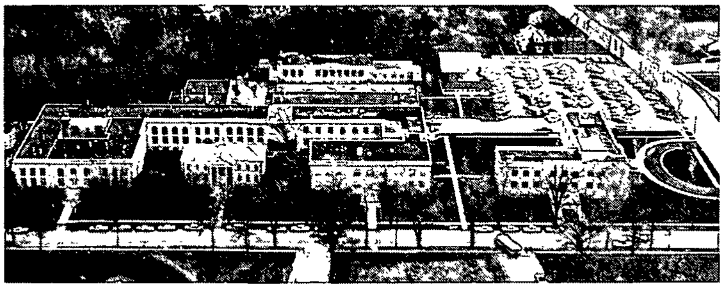

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IMPULSE DRYING AND PRESS DRYING: A CRITICAL COMPARISON

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IMPULSE DRYING AND PRESS DRYING: A CRITICAL COMPARISON

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ABSTRACT

Despite accounting for 85% of all U.S. paper and board production, conventional cylinder dryers are large, costly, slow, energy intensive, and have only a small, largely uncontrollable effect on paper properties. Impulse drying and press drying, two new high-intensity technologies, are being developed in response to the need for better drying systems. Press drying, originated for the Masonite process in 1925, has been under development in many laboratories for at least twenty years. Development of impulse drying was initiated in the late 70's with more intense development limited to the past two to three years. As a relative newcomer to the field, impulse drying is often treated in the literature as a variant of press drying. In reality, there are some very basic differences in the conditions used in the two processes, in the mechanisms of dewatering and densification, in overall performance, and, perhaps most importantly, in the technology base required for commercial implementation. Hence, impulse drying and press drying are distinct processes. This paper will provide a direct comparison of the two processes in all of these areas to show these distinctions. This information may help mills and suppliers assess the proper role of each process in future applications.

INTRODUCTION

For many decades, web consolidation in papermaking has been dominated by the separate and successive processes of wet pressing and hot surface or cylinder drying. Improvements in these processes over the past several years have been significant and, in the case of the long nip presses, quite dramatic. Further gains are likely to be incremental and small because of fundamental limitations in the dewatering and densification mechanisms involved. Large gains or dramatic improvements will require processes that invoke fundamentally new mechanisms. At least two of these are now on the commercial implementation horizon.

By combining the mechanical compression aspects of wet pressing with intense hot surface drying, Douglas Wahren (1) created the hybrid process of impulse drying. As is sometimes the case, the simultaneous application of two normally separate conditions yields a result which is much more than the sum of the individual parts. Several investigations of the process over the past few years (2-4) have clearly shown this by identifying at least three web consolidation mechanisms not common to either pressing or conventional drying. These are the basis of the excellent performance of the process.

Press drying, a process originated in 1925 (5), received initial consideration for use in paper dewatering in the early 60's (6) and again starting in the early 70's (7). Press drying also involves aspects of both pressing and drying. It, and impulse drying, a relative newcomer to the scene, are often considered as equivalent or very kindred processes. In reality, there are several differences in operating conditions, mechanisms, performance and implementation requirements. These differences are significant and require separate consideration of the processes for given applications. The purpose of this paper is to compare these processes as a basis for such considerations.

IMPULSE DRYING

Definition

Impulse drying is defined as the use of a long press nip with one hot roll to remove water from a wet paper web. In this process, the web is exposed to compressive or z-pressures up to 4-5 MPa and to hot surface temperatures generally from 175-400°C. For effective dewatering and densification under these conditions, exposure times typical of long nip presses are required. Hence, the proposed implementation technology is a long nip press with a direct, external heater on the press roll.

Mechanisms

From studies by Devlin (2), Burton (3), and Sprague and Burton (4), the mechanisms of impulse drying are well understood qualitatively. Further work is now underway to develop detailed mathematical models of the process. Figure 1 is a composite diagram showing the compressive pressure pulse, instantaneous heat flux, sheet internal temperatures, and an instantaneous density profile through the sheet for typical impulse drying conditions. Four time intervals, each involving a different set of mechanisms, are shown on the diagram.

In Interval 1, dewatering and densification are controlled by wet pressing mechanisms, i.e., volume reduction. Dewatering increases with increasing initial moisture ratio; densification decreases. The dewatering rate in this interval (2-4 ms) is equivalent to that for wet pressing, augmented slightly by thermal effects.

In Interval 2, the sheet is filled with liquid, except for a growing layer of pressurized vapor next to the hot surface. As this layer grows in size and pressure, it displaces liquid from the sheet and prevents evaporation of bound water in the vapor zone. Density development in the upper zone is retarded by the vapor-pressurized and saturated fibers; in the liquid filled zone, a density gradient is produced by fluid drag forces resulting from the vapor-induced fluid flow. Most of the heat energy for the whole process is delivered to the sheet in the first 5-10 milliseconds of this interval by a nucleate pool boiling heat transfer mechanism.

In Interval 3, the external pressure drops below the vapor pressure in the sheet. This allows flash evaporation of water from the fibers in the upper zone. Rapid drying, densification, and cooling of this zone, continued vapor displacement and heat transfer to the lower part of the sheet all result. Heat transfer to the sheet in this interval is limited to conduction and vapor convection mechanisms.

In Interval 4, the external pressure is reduced to zero, allowing continuing but unrestrained flash evaporation. Internal pressurization may cause bulking of the center zone of the sheet during this interval. Flash evaporation in Intervals 3 and 4 is driven mostly by stored energy, supplied during Interval 2.

The mechanisms of Intervals 2-4 are all unique to high-intensity drying. Vapor displacement and constrained flash evaporation (Intervals 2 and 3) are initiated at the hot surface and move through the sheet with time. Both are interrupted before completion by opening the nip. All three mechanisms are very intense and have a major impact on impulse dryer performance, as noted below.

Performance

Dewatering rates. Impulse drying removes water by wet pressing, by vapor displacement of liquid, by flash evaporation, and, if carried on long enough, by high-intensity evaporation. Water removal rates increase rapidly with initial moisture content and hot surface temperature. Pressure is relatively unimportant, but must be sufficient to contain the vapor pressure and compress the sheet to make liquid water available. Water removal rate decreases as the square root of nip residence time because the late stages of longer nips are dominated by the slower evaporation-based water removal processes. Typical water removal rates are in the range from 1500 to 8000 kg/hr/m^2 for a virgin kraft linerboard furnish and 2500 to 5000 for newsprint, Fig. 2. Corresponding numbers for conventional cylinder drying are about 15 kg/hr/m^2. Because of the strong dependence of impulse drying on water for its mechanisms, outgoing solids are virtually independent of ingoing solids, Fig. 3. It is truly remarkable that a single impulse drying nip of 25 ms duration can dewater a sheet from 30 to 76% solids. This impulse dryer could be used to replace a large part of the press section and most of the dryer section, as well. At 1500 mpm, the total machine direction dryer contact length would be only 0.63 meter.

Densification and paper properties. The average density of almost all impulse dried sheets is a strong, linear function of final solids up to at least 90%, Fig. 4, thus producing values much higher than those achievable under commercial wet pressing conditions. Furnish does affect the slope of this relationship, but it is only mildly sensitive to initial moisture content or drying conditions. Most strength properties are related to density in the usual way, Fig. 4, so high strengths are also achieved. For high-yield or recycled furnishes that are difficult to consolidate with conventional processes, impulse drying produces excellent dewatering, densification, and strength, Fig. 5. Clearly, use of impulse drying will allow

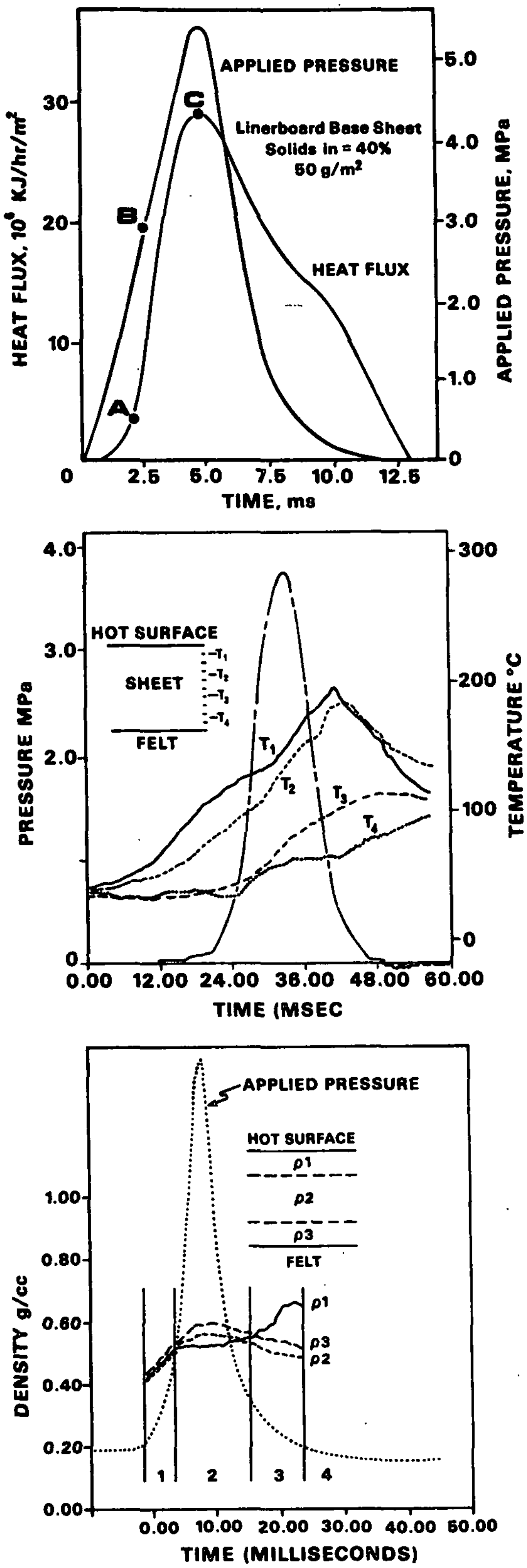

Fig. 1. Heat flux values, and sheet internal temperatures and densities measured during impulse drying.

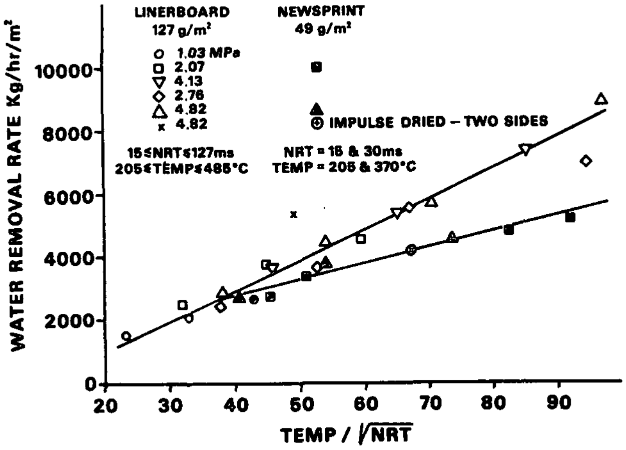

Fig. 2. Dewatering rates for a 127 g/m^2 virgin kraft linerboard base sheet and for a 49 g/m^2 newsprint sheet.

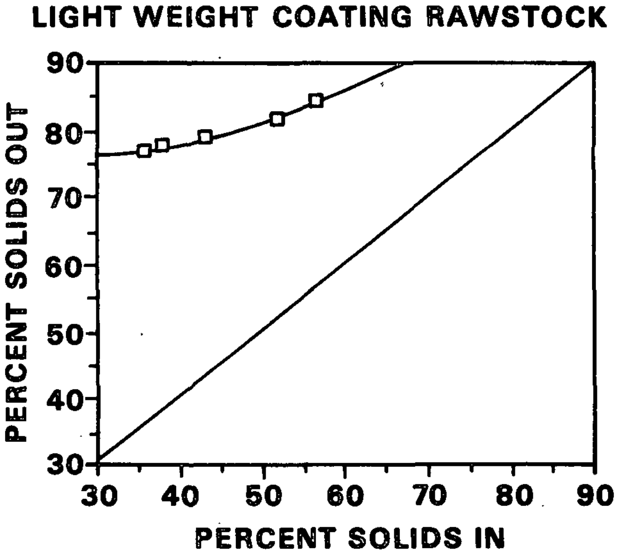

Fig. 3. Solids out versus solids in for a 55 g/m^2 coating stock. Dewatering from 30 to 76% solids was achieved in a single 25 ms nip.

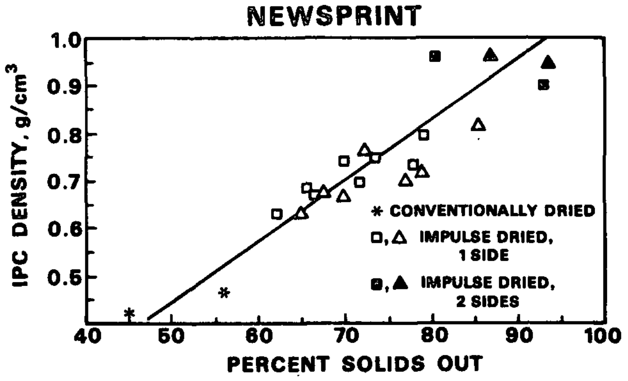

Fig. 4. Density versus exit solids for many different drying conditions, including two-sided drying.

the substitution of lower grade and, therefore, lower cost furnishes to meet current product specifications. Preferential strength at a given density, and improved sheet performance in high humidity and wet state tests all suggest the occurrence of hemicellulose and lignin flows, despite the short duration of the impulse drying event.

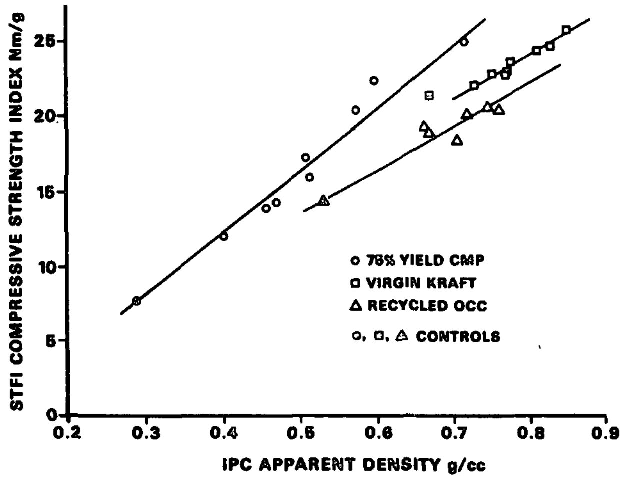

Fig. 5. STFI compressive strength values versus apparent density for three furnishes. All were dried under identical conditions. The control sheets were processed conventionally.

Strong dewatering force gradients, induced in the sheet and trapped by opening the nip before they subside, produce strong density gradients, as well, Fig. 1. As a result, sheets are highly densified near the hot surface, moderately densified next to the felt and fairly bulky in the center. Most strength properties relate directly to the average density, as noted above. Several other properties seem to be strongly influenced by the density gradient, however. These include unusually good opacity for the densities achieved, Fig. 6, tear strengths that are very high at a given tensile level, a breakdown in the normal scattering coefficient relationships, and a high bending stiffness, despite the low caliper. These unusual, but potentially beneficial relationships, have not yet been explored or exploited. The density profile is quite controllable by the selection of process conditions.

Impulse drying promotes surface smoothness, decreased air permeability, greater ink and water holdout, and greater surface strength (pick resistance). For many converting operations and end uses, these properties will be ideal; for others, less so. Direct evaluation of converting properties will take place in 1987 when large sheets of impulse dried paper become available.

Energy use. In impulse drying, liquid phase water removal may account for up to 80% of the total, and increases with increasing initial moisture content, initial sheet temperature and hot surface temperature. Energy is used initially for sensible heating of the wet sheet and later for heating the dry fiber, and for evaporation of the water that leaves as vapor. Specific energy consumption, i.e., kJ per kg of water removed, is quite low because of the large liquid component, and decreases rapidly with increasing moisture content, Fig. 7. Values of 550-1400 KJ/kg are likely for typical applications. This compares favorably with the 3500-4200 KJ/kg for cylinder drying and supports the use of high grade energy for water removal in the normal pressing solids range.

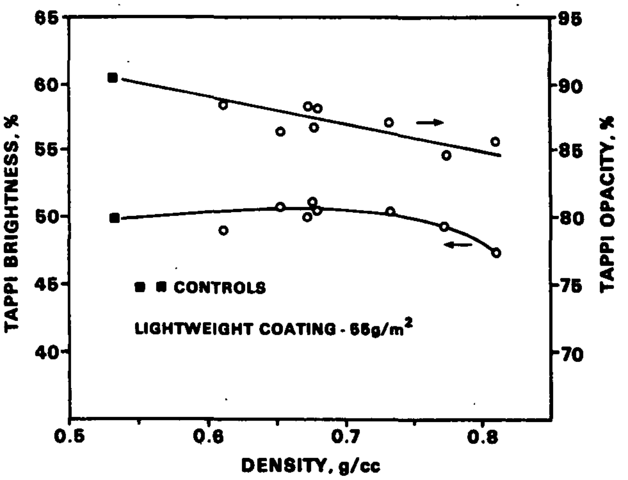

Fig. 6. Brightness and opacity values versus density for a furnish representative of a coating grade.

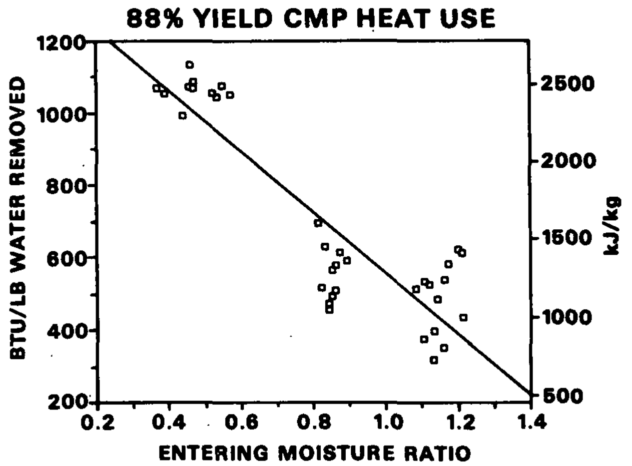

Fig. 7. Specific energy consumption versus initial moisture ratio for a high yield furnish used in a linerboard basis weight. The several pressures, temperatures, and nip residence times used to obtain these data account for the scatter about the line.

Implementation Strategies

Impulse drying requires pressures at or below those provided by any of several long nip press designs. Since nip residence time is a more advantageous variable than pressure, even longer nips operating at similar total loads may be advisable. Roll surface temperatures of up to 400°C will likely require direct external heating with hot gas or flame impingement. Electrical induction or infrared heating would be clean, controllable, and convenient, but probably inefficient. Felts that can withstand steady-state temperatures up to 100°C and wet pressing pressure levels, and impart a smooth surface to the sheet will be needed. Water handling capacity and rewetting will be important issues when impulse dryers are substituted for normal wet presses. There are existing technologies to meet each of these requirements, but they must be brought together in an integrated whole to achieve commercial implementation. Engineering challenges to implementation may include roll metallurgy, felt properties, safety, and efficient, controllable heat transfer.

PRESS DRYING

Definition

The term "press drying," coined to denote the combined application of pressing and drying, seems to encompass a range of technologies, but there are common features that serve to define the family. These include compressive pressures and hot surface temperatures sufficient to produce internal sheet temperature above 100°C, i.e., high enough to promote lignin and hemicellulose flow, and drying with the sheet under restraint to prevent or limit in-plane shrinkage. Generally the conditions used are more intense than those used in conventional drying but mild compared to those for impulse drying, and the sheets are dried to near the equilibrium moisture content. As a consequence of both, drying times are typically several seconds. Gottwald, et al. (6) did recognize the value of partial drying.

Mechanisms

Gottwald, et al. (6) used a continuous belt press with a steam heated cylinder for their experiments and commercial scale operation. Such devices are limited to compressive pressure of 100 kPa or so and hot surface temperatures of about 200°C. For the initial moisture contents typical of first or second press positions, used in their experiments, even the mild conditions above led to appreciable liquid phase dewatering. This was attributed to both normal wet pressing and vapor displacement mechanisms. Flash evaporation after the exit zone was also recognized. Exposure times are estimated to have been about 1-5 seconds, but even this long duration was not sufficient to fully dry the sheet.

Later and independent work on press drying was initiated in the early 70's. Since then, many workers throughout the world (7-15) have participated in the development of the process. Much of the early work used static platen presses, with both platens heated and a moist sheet sandwiched between sets of one or more screens on each side. Pressures in these devices ranged up to several megapascals, and temperatures ranged up to 400°C. Despite the high pressures and temperatures, the heat transfer rate is limited by conduction through the screens and vapor flow toward the hot surface rather than away, as in other processes. A quasi-equilibrium vapor generation rate is established by a balance between the heat addition rate and vapor pressure rise due to vapor flow through the screens. Sheet internal temperatures are limited by the vapor pressure rise controlled by the flow resistance of the screens, but can easily rise above 100°C. To a first approximation, these early embodiments of press drying involve intense vapor phase dewatering from an air-free sheet at an elevated temperature (above 100°C). There is little opportunity for vapor displacement dewatering or wet pressing, but bulk vapor flow under a total pressure gradient is likely.

Performance

Dewatering rates. In press drying water is removed primarily by high-intensity evaporation under total pressure, bulk flow conditions. Some vapor displacement and wet pressing are also possible, giving some liquid water removal. These mechanisms are much more effective than those of conventional drying and lead to drying rates up to 10 times higher. Gottwald, et al. (6) reported a water removal rate of about 200 kg/hr/m^2 for a belt pressure of 96 kPa and a steam pressure of 1.45 MPa (200°C), starting with a sheet estimated to be at 25% solids. Under these conditions, almost half of the water was removed as liquid.

Densification and paper properties. Much of the work on press drying has been devoted to the paper properties issue because this is the strength of the process. Some of the typical results were included in an earlier section on mechanisms. The major features of the process are the elevated sheet temperature, the full sheet restraint and the long exposure time, all promoting fiber softening and conformability and hemicellulose and lignin flow. Setterholm (7), Horn (12), and others have shown that these conditions lead to excellent densification, especially of recycled furnishes or high lignin furnishes such as high-yield red oak. Byrd (13) has studied the fundamentals of sheet property development in press drying and provided strong evidence for the role of lignin, and lignin and hemicellulose flow in producing the strength and moisture tolerance of press dried papers. He has also shown that these same mechanisms cause high lignin sheets to give greater strength than low lignin sheets at a given density.

Energy use. There are few, if any, direct measurements of the specific energy use or liquid dewatering fraction in press drying. Under typical press drying conditions, starting at the recommended initial moisture content of 40% (8), one would expect only modest liquid water removal. Hence, specific energy consumption would be only slightly better than that for conventional drying. Since conventional drying normally starts at 45-50% solids, total energy consumption might actually be greater. The quality of the energy used in this process is about the same as that used in conventional drying.

Implemention Strategies

The remarkable sheet properties developed in the static press dryers has prompted the development of several pilot test systems, aimed at achieving similar performance under the dynamic conditions of high speed paper machines. At least three systems (7,9,14) are in various stages of operation or development. Except for Lehtinen's (9) approach, all involve steam heated cylinders, one or more very short press nips, and a taut belt passing under the press rolls and around the cylinder to restrain the sheet. In the first short nip, the web is compressed and brought into intimate contact with the heated cylinder. At high speeds, the exposure times in these nips will be sufficient to compress the sheet, dewater it to a small extent and initiate heat transfer. Boiling may begin, but it will be interrupted quickly.

In the belt section, the sheet compression achieved in the nip will be largely retained by the belt. Boiling heat transfer will continue but will be limited to low rates by the available normal pressure. Likewise, the vapor pressure in the sheet and the corresponding temperature will be limited by the compressive pressure. Even though the vapor pressure is low, some vapor displacement of liquid should occur until the liquid seal on the belt side of the sheet is penetrated by vapor. Over this same time interval, the sheet internal temperature should be high enough to promote polymer flow and development of sheet properties. A second nip, displaced in the machine direction from the first, will further compress the sheet and make more liquid water available, possibly continuing or reinitiating the mechanisms. This embodiment should produce some liquid dewatering for energy efficiency, moderate dewatering rates because of both the liquid dewatering and the intensity of the evaporation process, and good paper properties because of the sustained elevated temperature, and z and xy restraint. Fairly long times will be required, however, because the dewatering rates will only be about one order of magnitude above those for conventional drying. Gottwald, Halsey and Williams (6) demonstrated all of these features on a slow speed, commercial scale machine in the mid-60's, although the polymer flow properties were not recognized at that time. Their device was much like some of those now being pursued.

In Lehtinen's approach (9), the sheet is sandwiched between two impervious belts, one heated and pressurized by steam, the other cooled by water. The steam supplies the compressive pressure and the heat energy; pressures and therefore temperatures are limited by the seals on the impervious belt and the load capacity of the structure. Pressures of 100-200 kPa would seem to be a practical upper limit. Air is displaced by steam as the sheet-screen sandwich passes into the belt section. There are no press nips in this system, although one could be placed ahead of it. The mechanisms should be similar to those in the taut belt cylinder portion of the other systems but more intense because of higher temperatures and compressive pressures. Exposure times will still need to be long.

THE COMPARISON

Impulse drying employs much higher pressures and moderately higher hot surface temperatures which, together, produce process rates which are high enough to allow very short exposure times. Hence, impulse drying can be implemented commercially by combining existing long nip pressing technology and existing heat transfer technology. In contrast, press drying uses modest pressures and temperatures yielding low process rates which require longer exposure times. Achieving even modest pressures for long time intervals (relative to typical paper machine events) is a formidable task and the principal impediment to achieving press drying at full commercial speeds. Most pilot systems show poorer performance than the static laboratory devices (15).

Both processes have an element of wet pressing and vapor displacement, but the rate and extent of each are much greater in impulse drying. Flash evaporation of bound water under constraint is an important ingredient of both dewatering and densification in impulse drying; if it occurs at all in sheets press dried to equilibrium moisture levels, it is a very modest contribution. A similar statement holds for unconstrained flash evaporation. High intensity evaporation is the principal water removal process in press drying; it is a negligible contributor in impulse drying. Hence, about the same mechanisms are present in both processes, but with very different relative magnitudes. This has tremendous significance for implementation, energy consumption, and property development.

Both processes are capable of producing high average densities with correspondingly high strengths, but impulse drying is favored in this regard. Significant fiber softening and flow of the lignin and hemicellulose components also seems to occur in both processes, with the extent probably controlled by the final dryness achieved in impulse drying. This gives both processes an excellent ability to produce strong and moisture resistant products from high yield and other low cost furnishes.

Press drying produces a relatively uniform z-direction density profile; impulse drying produces a very nonuniform but controllable profile. The resulting density gradients give some new and very favorable property characteristics, including high tear strength and surprisingly high opacity. In some cases, however, the nonuniform density may be a disadvantage.

In impulse drying, vapor displacement produces dewatering without densification (volume reduction). This, plus the fiber collapse produced by flash evaporation can be used to produce sheets with dense, stiff skins, and a bulky center for bending stiffness, and z-direction compressibility, an ideal sheet for printing or boxboard. If properly controlled, the vapor displacement mechanism may produce very high dewatering rates and dryness but leave a bulky sheet structure.

Both processes produce smooth, more closed sheet surfaces and only modest changes in optical properties. Impulse drying produces very well bonded sheet surfaces, greatly reducing the tendency for dusting, linting and other conversion-related surface deficiencies. Except for the work of Horn and Setterholm (7), who showed excellent conversion properties for press dried, red oak linerboard, data on converting properties are scarce.

Specific energy consumption should be much lower in impulse drying because of the high degree of liquid dewatering, although there are no press drying numbers available for direct comparison. Impulse drying will require a higher grade of energy.

In commercial practice, an impulse dryer is expected to consist of a long nip press with direct, external heating of a plain press roll. Recent data, Fig. 3, suggest that the impulse dryer should replace one or two presses and much of the dryer section, depending on grade. In most cases, impulse drying beyond 70-80% solids will be inefficient unless extreme property development is required. Hence, some cylinder drying in the high dryness range will be typical.

There are no known recommendations in the literature for locating the press dryer in the paper machine, although 40% initial solids is recommended for optimum property development (8). Most press drying experiments have produced fully dried sheets. Gottwald, et al. (6) started press drying at much lower initial solids levels and terminated the process well before the desired final dryness was achieved. The low process rates in press drying will require an extremely long dryer surface if part of the press section and all of the cylinder dryer section are to be replaced.

SUMMARY

In summary, both processes offer significant advantages over conventional technology, particularly in influencing paper properties. Impulse drying offers additional advantages in dewatering rates, small equipment size, ease of implementation, specific energy consumption, property control, density profiling, and, probably, in total density development. Impulse drying will probably work very well for initial solids levels from 20-50%. Press drying will use lower grade energy and, because of the much longer exposure time, may promote more lignin flow.

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