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IMPULSE DRYING OF PAPER: A REVIEW OF RECENT RESEARCH

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ABSTRACT

Impulse drying is a new process for drying paper that holds great promise for reducing the energy consumed during the manufacture of paper and similar web products [1-4].

About half of the paper manufactured in the U.S.is comprised of heavyweight grades. Early attempts to commercialize impulse drying for these grades were complicated by the occurrence of sheet delamination [4-6]. Research at the Institute of Paper Science and Technology (IPST) has demonstrated that ceramic coated press rolls have the potential for controlling heat transfer to the wet sheet, thereby allowing delamination-free impulse drying [7-16].

Recent pilot dryer experiments demonstrate that heavyweight grades can be impulse dryed to 60% solids in a 40 millisecond nip, resulting in a 300 kWh per ton energy savings over conventional drying [13-16]. With full implementation, at least 6,000,000 barrels of imported oil could be saved each year. These studies also confirm a 25% improvement to critical paper physical properties which will allow energy saving fiber substitution strategies.

This paper reviews many of the key research findings that form the basis for plans to commercialize this important new technology.

BACKGROUND

In conventional drying, a series of steam heated cans raises the temperature of the sheet and removes water by evaporation. Evaporative drying represents a major fraction of the total energy used in papermaking.

Impulse drying was conceived to increase papermaking energy efficiency by reducing the amount of water to be removed by evaporative drying. To achieve this, the heated press roll shown in Figure 1 would be used in combination with a long nip press. In the press nip, a small amount of steam is produced which assists in moving water from the paper to the felt.

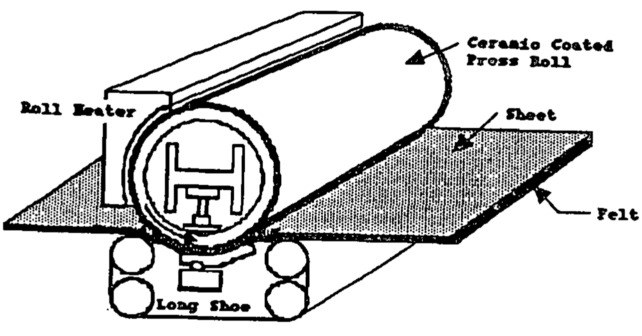

Figure 1 Impulse Dryer Concept.

One application of the impulse dryer would be to place it between the third press and the cylinder dryers of a paper machine, as shown in Figure 2. In new machine installations about half of the number of conventional cylinder dryers would be required resulting in a 300 kWh/ton energy savings. In retrofitted installations, where the machine is dryer capacity limited, an impulse dryer could be used to achieve simultaneous machine speed and energy efficiency improvements.

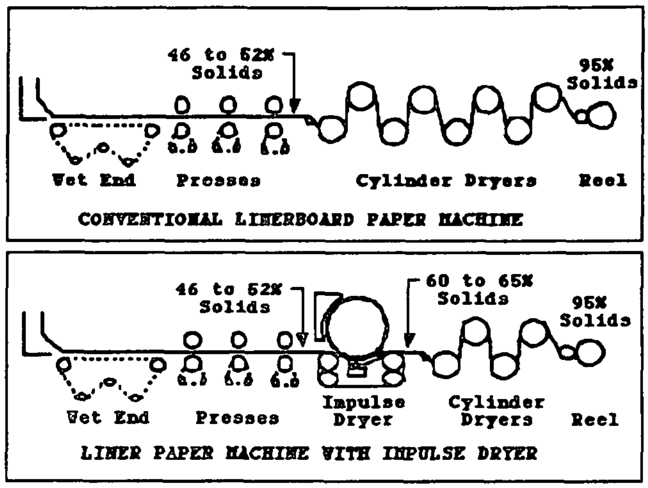

Figure 2 Conventional Paper Machine And Paper Machine Modified With An Impulse Dryer.

SOLVING THE SHEET DELAMINATION PROBLEM

Review Of Laboratory-Scale Experiments

A troublesome component of the impulse drying process is sheet delamination. As the nip depressurizes, superheated water remaining in the sheet flashes to vapor and escapes through the sheet surface. When excessive amounts of energy are transferred to the sheet, drag forces resulting from the escaping vapor can be high enough to overcome the cohesive forces holding the sheet together and the sheet delaminates.

To eliminate sheet delamination, IPST has taken the approach of controlling energy transfer to the sheet. Low "thermal mass" ceramic press roll coatings were developed to reduce heat transfer to the sheet while maintaining high surface temperatures during early stages of the process. Hence, most of the transferred energy is used to form steam which displaces liquid water, while excessive steam formation leading to delamination is avoided.

Early laboratory scale work with a machinable (Cotronics) ceramic showed the sheet exit temperatures were reduced by replacing the steel platen with a low "thermal mass" ceramic [7,8,12]. Figure 3 shows internal sheet temperatures during impulse drying as measured by thermocouples placed at various locations within a sheet of linerboard. The steel platen resulted in internal sheet temperatures in excess of 100°C in as short as 10 milliseconds. The machinable ceramic restricted heat transfer to the sheet so that internal sheet temperatures were substantially reduced.

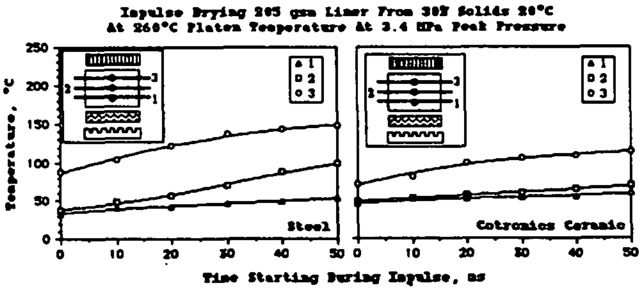

Figure 3 Sheet Internal Temperature During Impulse Drying Using Steel and Machinable (Cotronics) Ceramic Platens.

Using a more practical plasma sprayed ceramic coated platen, water removal was found to be dependent on initial temperature and impulse while being independent of platen thermal properties [12]. This is a key result, as it suggested that high water removal rates could be maintained while reducing excessive energy transfer to the sheet that was suspected to cause sheet delamination. Figure 4 shows a comparison of water removal, normalized to the dry weight of the sheet, as a function of impulse drying temperature and peak impulse pressure for steel and plasma sprayed ceramic platens.

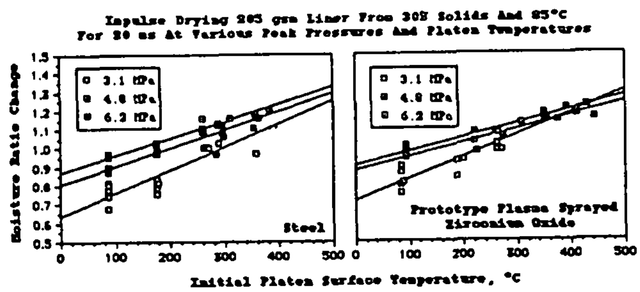

Figure 4 Water Removal Achieved With Steel And Plasma Sprayed Ceramic Platens At Similar Process Conditions.

In the same laboratory scale experiments, critical impulse drying temperature, above which sheet delamination occurs, was found to be influenced by platen thermal properties and by peak pressure (impulse). As shown in Figure 5, the ceramic surface could be operated at higher temperatures and pressures than the steel platen, without inducing sheet delamination. As a result, more water could be removed from the sheet.

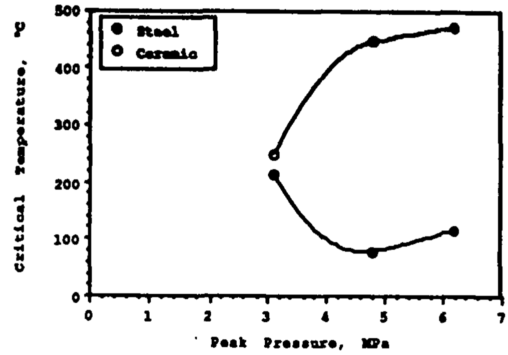

Figure 5 The Effect of Platen Material And Peak Pressure (Impulse) On Critical Impulse Drying Temperature.

To help explain this effect, additional laboratory scale experiments were conducted in which surface thermocouples were used to determine how platen thermal properties effect energy transfer to the sheet [10]. Figure 6 shows that energy transfer was dependent on peak pressure (impulse) for high "thermal mass" steel surfaces and independent of peak pressure (impulse) for the low "thermal mass" prototype platen. Notice also that at a given temperature and impulse, the ceramic surface transfers less energy to the sheet than the steel platen. We have postulated that ceramic surfaces avoid sheet delamination by decoupling heat transfer from wet pressing effects. As a result, the ceramic surface can be operated at higher pressures without overheating the sheet. Concurrently, by transfering less energy, the ceramic surfaces can be operated at higher temperatures.

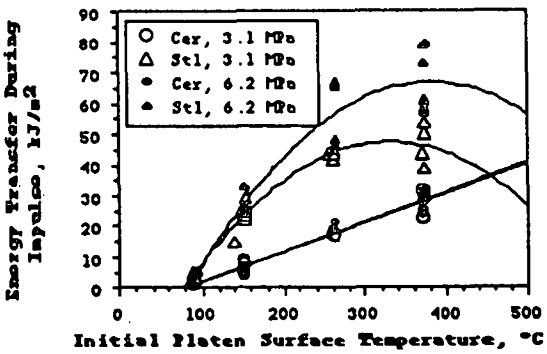

Figure 6 The Effect Of Platen Material and Peak Pressure (Impulse) On The Energy Transferred To The Sheet During Impulse Drying.

Laboratory experiments showed that ceramic platens could be operated at higher temperatures and pressures without inducing sheet delamination. Dried under these conditions, apparent sheet density could be increased to higher levels resulting in higher strength as measured by elastic modulus, STFI compression strength, and burst strength. Figure 7 demonstrates that while ceramic surfaces achieve higher density, the relationship between bond strength (specific elastic modulus) and apparent sheet density was independent of platen material.

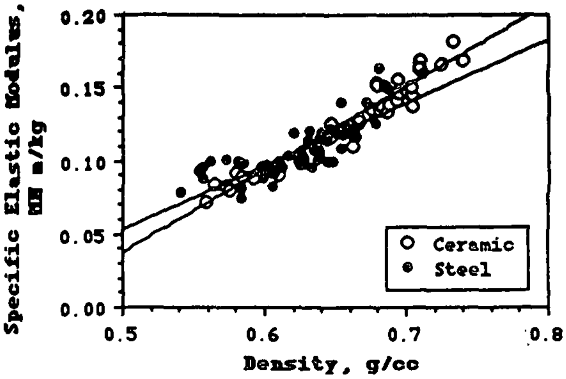

Figure 7 Bond Strength As Measured By Specific Elastic Modulus As A Function Of Sheet Density For Different Platen Materials.

Micrographs of crosssections of impulse dried sheets were analyzed using an image analyzer to determine the effect of platen material, temperature, and pressure on out-of-plane density profile. Figure 8 shows density profiles for sheets impulse dried using a steel platen. It was observed that as long as temperatures were below the "critical temperature" no internal bulking was observed. It was also observed that the average density and density in contact with the heated platen both increased when the platen temperature and pressure were increased.

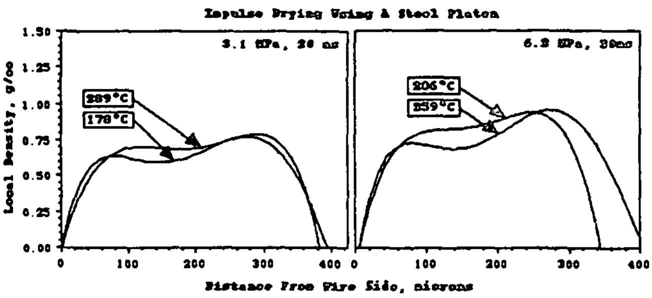

Figure 8 Internal Density Profiles Of Sheets Impulse Dried With A Steel Platen At Various Peak Pressures And Temperatures.

As shown in Figure 9, similar results were observed using the prototype plasma sprayed platen, suggesting that sheet density profiles are independent of platen thermal properties.

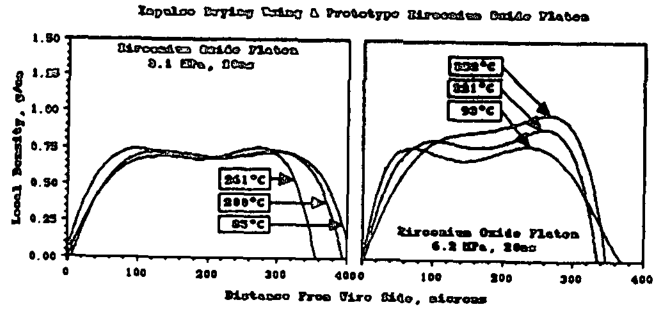

Figure 9 Internal Density Profiles Of Sheets Impulse Dried With The Prototype Ceramic Coated Platen At Various Peak Pressures And Temperatures.

Review Of Pilot-Scale Experiments

Over the past year, the focus of impulse drying research has shifted to demonstrating the process on the Institute's pilot impulse dryer. A schematic of the pilot impulse dryer is shown in Figure 10. The internal structure of the plasma sprayed ceramic roll coating was similar to the platen prototype. The ceramic coating had an effective "thermal mass" of 2000 $W \cdot s^{1/2}/m^2 \cdot °C$. The roll was heated by an external source of infrared radiation as controlled by an infrared sensor. The sensor was positioned just prior to the nip (within 0.38 m) to record the temperature of the roll and to serve as the input to the temperature controller. The controller adjusted the output of the infrared roll heaters to maintain a constant ingoing roll surface temperature.

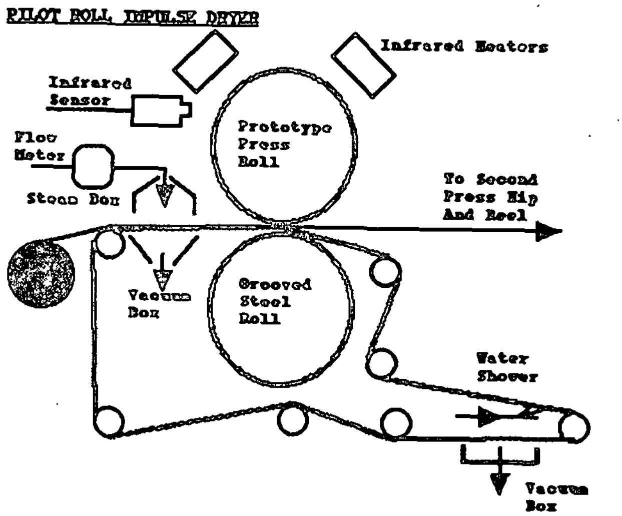

Figure 10 Schematic Of The IPST Pilot Impulse Dryer Roll Press.

Sheet preheat temperature was adjusted using a steam box in combination with a vacuum box. The steam preheating system was calibrated for each change in furnish and refining level to control ingoing sheet temperature between 90°C and 100°C and to account for water addition to the sheet.

Felts used in the experiments were constructed of a nylon base and a Nomex working surface. The felt was conditioned by spraying water on both of its sides and removing excess water with a vacuum. This washed and cooled the felt and provided a consistent felt moisture ratio of between 0.15 and 0.20.

In the experiments, the nip was set and balanced to a peak pressure of 6.2 MPa as verified using Fuji pre-scale LW pressure-sensitive film. Based on a measured nip width of 20 mm at 6.2 MPa, a dryer speed of 30 m/min corresponded to a dwell time of 40 ms.

To show the benefit of impulse drying over single-felted wet pressing, impulse drying experiments were typically conducted over a range of ingoing roll surface temperatures from 100°C to 430°C. To prevent the web from sticking to the heated roll at low temperatures, a polymeric release agent was applied to the ceramic roll.

To simulate oriented commercial linerboard, a slow speed web former was used to produce rolls of wet paper to be used as feed to the pilot dryer. After pressing the paper to a desired starting dryness, the paper was threaded into the pilot impulse dryer at slow speed with the nip open. After threading, the nip was closed, and the steam and vacuum were turned on. Once the paper was threaded through the press, the controller would uniformly and quickly bring the machine up to the desired speed and hold that speed until the conclusion of the run. At the conclusion of the run, samples of the impulse dried sheet were tested for outgoing solids and finish dried so that sheet physical properties could be determined.

A key objective of the pilot trials was to determine the influence of furnish variables on impulse drying performance. As sheet permeability influences conventional pressing processes, sheet permeability was investigated. Using sheet permeability test equipment developed at the Institute, the out-of-plane permeability of single-ply linerboard was measured over a range of refining and pressing [14]. From permeability vs. sheet porosity data, hydraulic specific surface was determined. A low specific surface means that the sheet is highly permeable. Figure 11 shows the important result that increased refining increases specific surface, while pressing decreases specific surface. It is desirable to increase the permeability of the sheet as introduced to the impulse dryer. Therefore, refining should be minimized and pressing should be maximized.

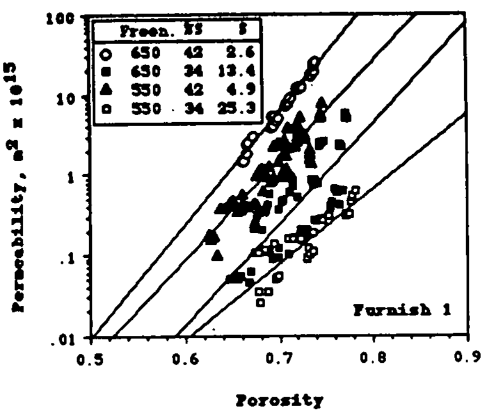

Figure 11 The Effect Of Refining And Pressing On The Permeability Of Single-ply Linerboard Sheets.

Pilot experiments performed at ingoing solids of less than 40% resulted in outgoing solids not significantly above that which can be obtained from conventional pressing technology. At ingoing dryness above 40%, substantial improvements over conventional pressing were demonstrated. Figure 12 shows the results of permeability measurements made on two different linerboard furnishes obtained from two different paper manufacturers [16]. The furnishes were refined to freeness from 550 ml CSF to 740 ml CSF and pressed to 42% solids prior to testing.

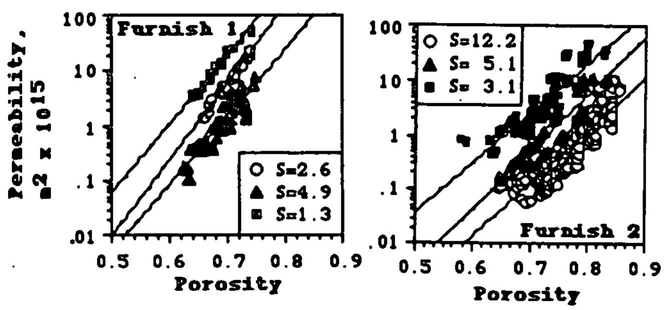

Figure 12 The Permeability Of Sheets Formed From Two Furnishes Refined To Three Levels And Pressed To 42% Solids.

The single-ply linerboard sheets for both furnishes were impulse dried on the IPST pilot impulse dryer. As shown in Figure 13, the critical impulse drying temperature decreases with increasing sheet specific surface [14,16]. Also shown is a comparison of impulse drying at the critical temperature to single-felted wet pressing at the same impulse. Clearly, the maximum benefit from impulse drying occurs when sheet specific surface is minimized.

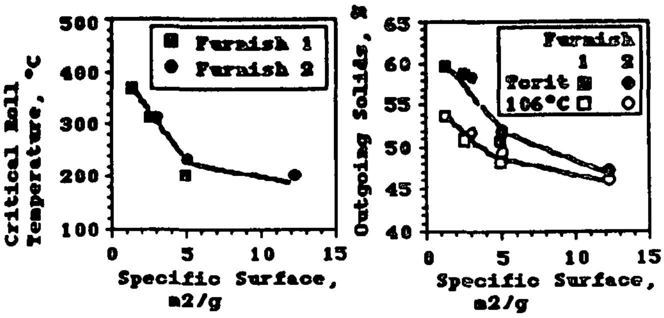

Figure 13 The Effect Of Sheet Specific Surface On The Critical Impulse Drying Temperature And On Outgoing Solids.

Water removal is dependent on press surface temperature, impulsel, and the specific surface of the sheet. With a ceramic press surface, energy transfer during impulse drying is only dependent on press surface temperature as shown in Figure 14 [15,16].

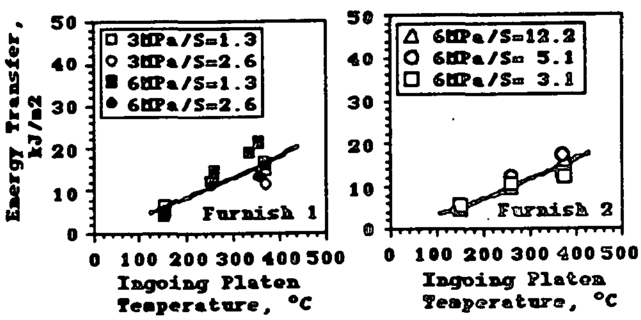

Figure 14 Energy Transferred To The Sheet During Impulse Drying For Various Furnishes, Peak Pressures and Sheet Specific Surface.

Results Of Process Simulation

Application of impulse drying to commercial width and commercial speed paper machines will require use of a crown-compensated roll and a long press shoe as shown in Figure 15. In order to achieve nip residence times of 40 milliseconds at commercial machine speeds of 2500 fpm, press shoes will need to be 20 inches long. As the current state of the art is about 11 inches, longer shoes will require development. To achieve uniformly high pressures across the width of a commercial paper machine, internal hydrostatic support elements will need to be developed to withstand high temperature and high pressure.

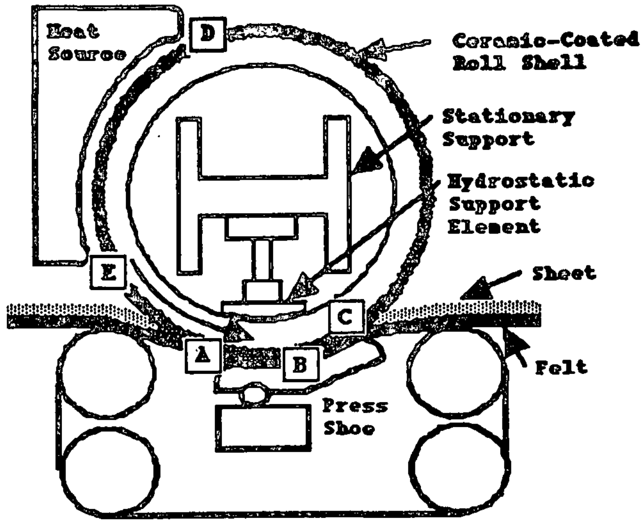

Figure 15 Schematic Of A Proposed Commercial-Scale Impulse Dryer Showing: A) The Start Of The Nip, B) Mid-Nip, C) The End Of The Nip, D) The Start Of The Roll Heating Zone, E) The End Of The Roll Heating Zone.

By using experimental heat flux measurements, a numerical model of heat transfer in the ceramic coated roll was developed [15]. The model was used to explore the potential benefits of various ways of heating the ceramic coated press roll. Figure 16 shows some of the results of that study. The symbols represent various locations along the circumference of the press roll as shown in Figure 15. Figure 16 shows that heating the roll near its outer surface reduces the magnitude of temperature fluctuations at the ceramic/iron interface. As thermal stresses are dependent on these temperature fluctuations, external heating would be preferred for maximum coating durability. Because the interface temperature is reduced, external heating also reduces heat loss to the inside of the roll which improves roll heating efficiency.

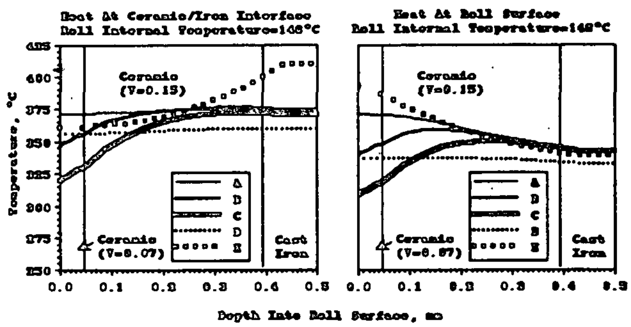

Figure 16 Calculated Temperature Profiles In A Ceramic Coated Press Roll As Heated By External And Internal Sources.

From the model, energy savings were calculated as the energy content of steam that does not have to be used to heat conventional cylinder dryers minus the energy content of the fuel used to produce the electric power required to heat the impulse dryer. It was assumed that 1.5 kg of cylinder dryer steam are required per kilogram of water evaporated by the cylinder dryer. It was also assumed that the roll would be electrically heated. The production and distribution of electricity were assumed to be 30% efficient.

Figure 17 shows that energy savings of about 350 kWh/metric tons of paper can be saved over conventional drying. These significant energy savings can be realized at even low internal temperatures corresponding to roll heating efficiencies of only 50%.

Figure 17 also shows the results of a similar calculation in which the reference process was taken as single-felted extended nip pressing as predicted by our impulse drying experiments at 106°C reference temperature. In the calculations, the critical impulse drying temperature was chosen at each value of specific surface. The figure shows that relative to single-felted extended nip pressing, energy savings can be realized up to a specific surface of about 10 m^2/g.

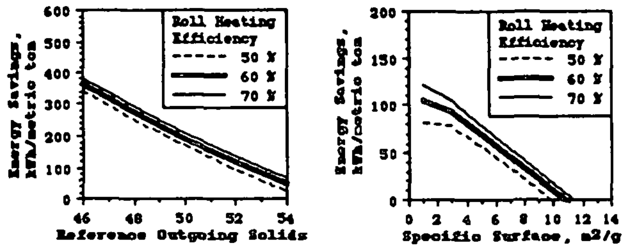

Figure 17 Energy Savings As A Function Of The Outgoing Solids Of The Reference Pressing Process And The Specific Surface Of The Sheet.

In Figure 18, the results of Figure 17a are expressed as a production cost savings in units of U.S. dollars per metric ton of paper produced. Clearly, the cost savings depends on the cost of electric power to heat the roll and to a lesser extent on the efficiency of roll heating. In the U.S., the cost of on-site electric power production would be calculated as the cogeneration fuel cost ranging from 0.01 to 0.02 U.S.$/kWh. Therefore, compared to conventional drying, energy cost savings of about 5.00 U.S.$/metric ton could be realized.

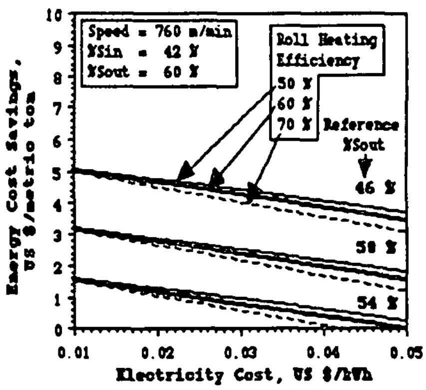

Figure 18 Energy Savings As a Function Of Cost Of Electricity And Roll Heating Efficiency For Various Reference Pressing Processes.

PLANS FOR COMMERCIALIZATION

Based on the results of these studies, a plan for commercialization of impulse drying has been formulated. As it is currently envisioned, commercialization will require a joint technical effort between IPST, paper machine builders, and paper manufacturers with the support of the U.S. Department Of Energy and other interested organizations such as the Electric Power Research Institute and the American Paper Institute.

Commercialization of impulse drying will require continued research. Research is needed to further improve the thermal properties of the ceramic coating and optimize the design of the press roll for maximum energy efficiency and roll durability. Research is also needed to provide a strong base of understanding from which users can predict process performance.

Continued development will be required since impulse drying technology utilizes relatively extreme operating conditions close to the present limits of support technology. Technical issues associated with the use of longer press shoes, higher press loads, higher internal press roll temperatures, and more durable felt designs will need to be addressed.

Transfer of impulse drying technology to the pulp and paper industry will require that the needs and concerns of machine suppliers and paper manufacturers be identified and met. Machine builders will need to develop confidence that they will be able to guarantee the performance, durability, and cost-effectiveness of the technology to their customers. Similarly, their customers, the paper manufacturers, will need to see that impulse drying performance, durability, and cost-effectiveness is superior to conventional technology yet compatible with their raw materials, facilities, and the requirements of their product.

Impulse drying is a leading edge technology. Consequently, predicting all of the technical issues that will have to be faced during the process of commercialization is very difficult. By involving machine builders and paper manufacturers, the Institute will not only minimize the risk of overlooking import issues but also effect technology transfer.

The commercialization of impulse drying can be divided into a three part program. The first part can be described as a series of proof of principle experiments that are designed to demonstrate that the principles of the process are sound and that there are sufficient potential benefits to be derived from the process. While additional experiments will be carried out in the 1992-1993 time frame, the major proof of principle experiments will be completed by the second quarter of 1992. The second part of commercialization focuses on perfecting the process. Conditions that closely conform to commercial practice will be used to develop a practical commercial process. Issues such as component durability, operating procedures, and limitations will be explored. This part of the project will identify equipment modification requirements for implementation in the commercial-scale phase. It is important that fundamental process research and development continue during this part of the program so that the results can be codified into the existing knowledgebase. A key objective will be the development of machine vendor and paper manufacturer confidence in the performance of the process and the various equipment subsystems. A key aspect of this part of the program will be developing a continuous commercial speed impulse dryer for experiments on a pilot paper machine. As significant quantities of paper will be produced in these experiments, the paper manufacturer will have a good opportunity to investigate the performance of the paper in various converting operations. Pilot paper machine trials could be completed by the fourth quarter of 1994.

The third part of commercialization consists of full-scale experimentation and evaluation of the technology in a commercial environment. The purpose is to document the performance of the process and to solve technology transfer problems as they arise. From the paper manufacturers viewpoint, the key issues will be process performance in terms of paper property development, water removal, energy utilization, and equipment uptime. Paper property development will be assessed in terms of measurable properties and also in terms of the performance of the paper in its final application. Water removal and energy utilization will also be monitored to provide a clear understanding of the economic impact of the process. Finally, the impact of the process on paper machine uptime will be assessed. This part of the commercialization plan will be completed at the end of a 360 day/year commercial demonstration by the fourth quarter of 1997.

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