IMPINGEMENT DRYING OF PRINTING PAPERS AT ELEVATED TEMPERATURES

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ABSTRACT

The first impingement drying unit was installed in a production machine in spring 1999, where it has operated since. Before the commercialization of the OptiDry impingement dryer, an extensive research program was carried out. All the main printing paper grades as well as heavier board grades have been studied on pilot machines during the past years.

Initially, impingement drying was planned to be restricted to air temperatures not exceeding 300^{o}C, because this was considered to be the maximum temperature which the fabrics could withstand. Paper quality in high temperature impingement drying has also been thought to be a limiting factor. Higher temperatures are desirable since they facilitate higher drying rates and more efficient use of energy which results in more effective drying and a shorter dryer section.

The studies described in this paper were carried out on pilot machines located in Jyväskylä. The first machine consists of a cylinder dryer group followed by an impingement dryer unit, which operates at speeds up to 2400 m/min. The other impingement dryer unit is installed on Rautpohja's pilot machine #2 dryer section, which runs up to 2500 m/min.

The results of the high temperature impingement drying studies performed are presented in this paper. Evaporation rates at temperatures up to 450^{o}C are given together with the effects of high temperatures on paper quality (rheological and optical). The method for preventing fabric damage is also discussed, as well as the improved energy efficiency at higher temperatures.

INTRODUCTION

Paper machine speeds for almost all grades have continued to rise in recent years. Since drying capacity in conventional drying is directly proportional to speed, this has led to increasingly long dryer sections and machine rooms, and increasingly higher investment costs associated with this. In addition, the increased number of web release points from dryer cylinders result in poorer runnability. During the last ten years the trend towards longer dryer sections has also been caused by the introduction of single-felted dryer sections which have better runnability compared to double-felted dryer sections. This is why more efficient drying methods have been studied, with impingement drying being one of the most promising solutions.

Impingement drying combines a vacuum roll and an impingement hood. Before Burgess et al., /1, 2/, introduced the Papridryer, which he ultimately tested on a commercial newsprint machine in Canada in early 1970, impingement drying was a long known drying technology, employed on Yankees dryers, to dry tissue paper. The Papridryer had a suction roll with seals, covered by a coarse fabric on the roll surface. Some of the air impinging onto the paper surface, aided by internal vacuum, percolated through the web whilst the remainder bounced off the surface and was re-circulated. Both of these techniques differ from the impingement drying technique presented here. Papridryer had a very open vacuum roll and utilized through air drying using air temperatures and velocities of 400^oC and 85 m/s respectively, while Yankee dryers presented a smooth, hot and impervious surface to the web. Tissue drying requires no dryer fabric while through air drying does. The impingement drying concept presented in this paper has a "normal" vacuum roll with a larger diameter, an arrangement well-known in today's single-felted dryer sections.

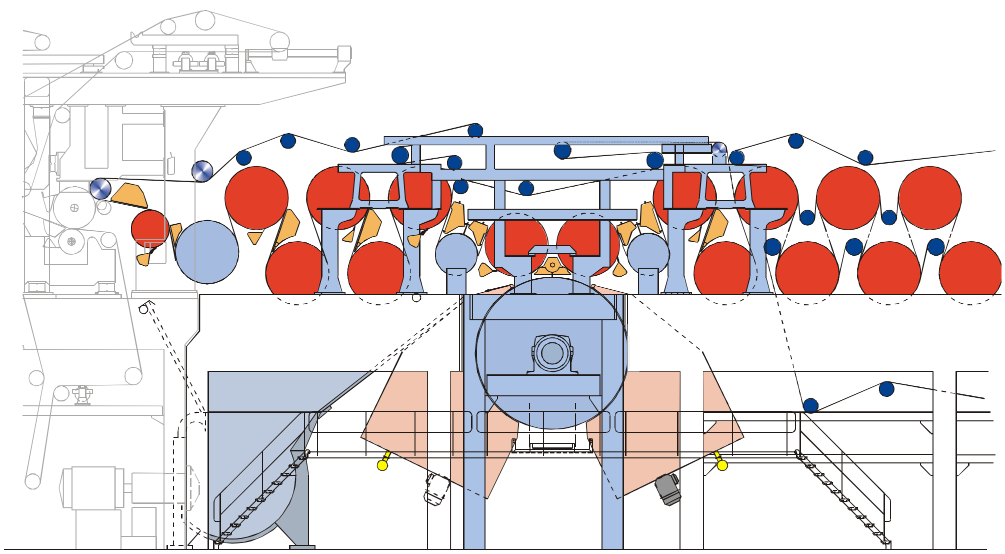

Figure 1. Nordland Papier PM1 impingement dryer layout.

The first commercial impingement dryer unit (OptiDry) was installed at Nordland (NP1) in May 1999 where it has operated since, **Figure 1**. It is located in the second dryer group and consists of a large vacuum roll and two separately controlled integrated hoods. Integration of blowers inside the hoods saves a lot of space because no external piping is required to circulate the air.

PILOT MACHINES USED IN TRIALS

Impingement drying studies presented in this paper have been carried out on two pilot machines in Jyväskylä. The first of these, shown in **Figure 2**, was designed specifically to study impingement drying and web runnability.

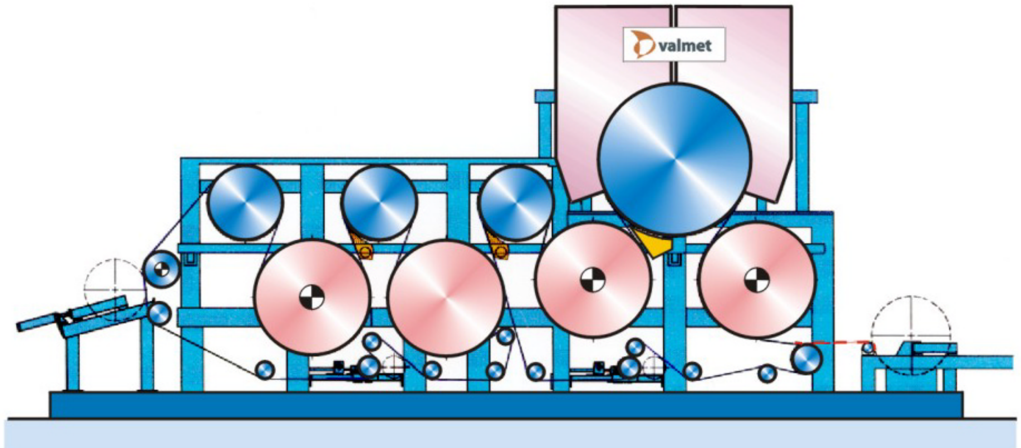

__Figure 2. Impingement drying pilot machine at VTT Energy.__

It has two dryer groups comprising 1.8 m diameter electrically heated cylinders and a 2.4 m diameter impingement roll with an air hood. The machine can run at speeds from 30 m/min to 2400 m/min. Impingement air velocity can be varied from 50 m/s to 150 m/s and impingement air temperature from 150°C to 450°C. Impingement air moisture can also be changed within a wide range. Paper used in trials has been made of commercial furnishes, produced at different pilot paper machines in Finland and Sweden. Wet paper rolls with an initial dry content before drying of about 42 to 50%, were run from unwinder through the two dryer groups to the reeler. Moisture measurements were made with infrared sensors and from paper samples in the laboratory.

The second pilot dryer used for the studies is located in Valmet's Rautpohja # 2 pilot machine, shown in **Figure 3**, started up in 1996. This machine also has a top side impingement unit but one which operates integrally with a full scale pilot machine producing a continuous web.

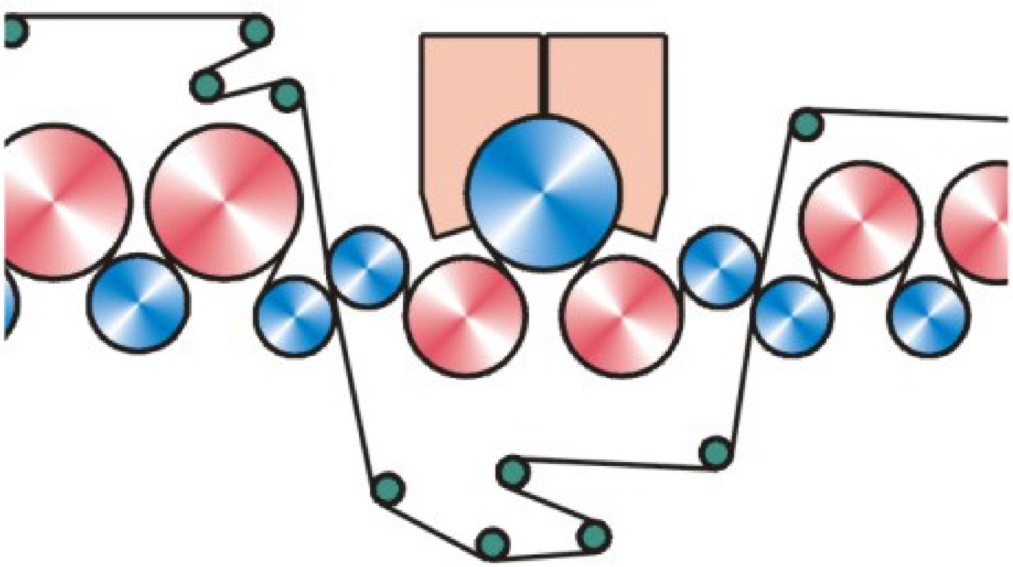

__Figure 3. Rautpohja pilot machine #2.__

Machine speed can be varied from 600 m/min to 2500 m/min with the following drying parameters - impingement air velocity from 60 m/s to 140 m/s and impingement air temperature from 150°C to 450°C. Impingement dryer in Figure 3 has been run at speeds over 2100 m/min.

The studies carried out on these pilot units focused on three main issues – measurement of drying efficiency of different paper and board grades, study of the effects of drying conditions on paper quality and, finally, assessment of web runnability.

DRYING WITH HIGH IMPINGEMENT AIR TEMPERATURES

During the past years dozens of trials have been run at many different drying conditions on many different paper grades. The results of all these tests have produced an overall drying performance window shown generally in **Figure 4**.

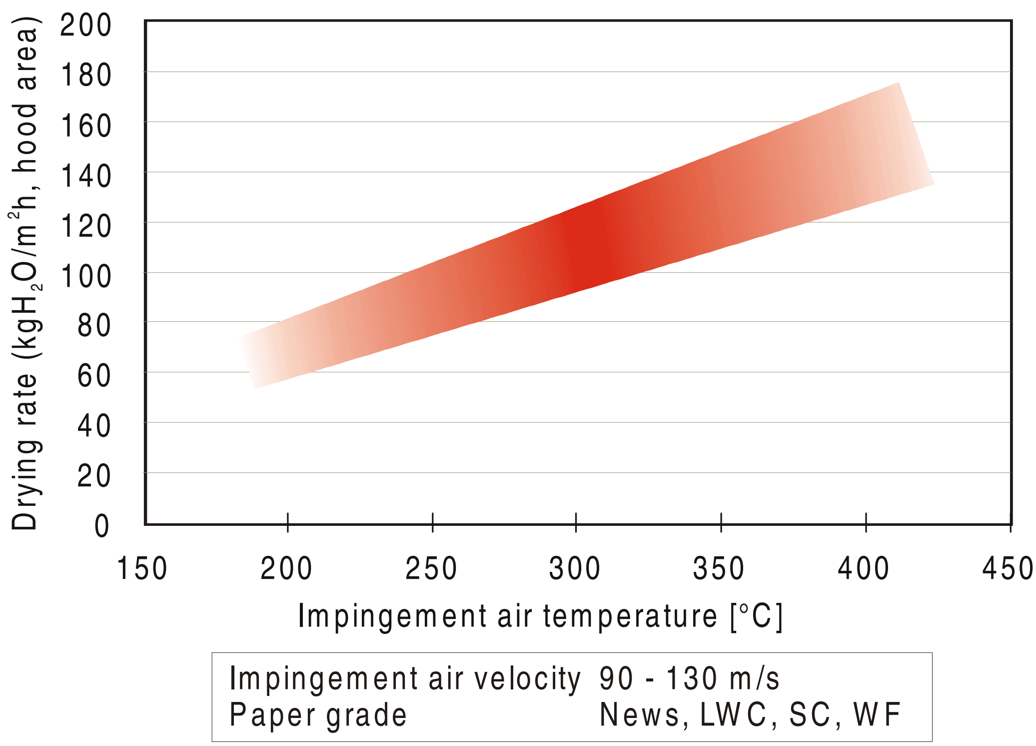

Figure 4. Drying capacity of impingement drying in general.

The figure shows the average drying rate in a constant drying rate period, which covers dry content up to 85%. Above this, the drying rate decreases rapidly because bound water inside fibers is more difficult to remove than free water present at lower dry content. The "window" presented in Figure 4 is obtained through several trials and includes a wide range of impingement velocities and temperatures. However, it gives an average value for achievable drying rate in impingement drying. It can be said that drying rates for different paper grades are all roughly the same. For papers having low permeability, the drying rate is lower than presented in Figure 4.

Drying Rate

The above average drying rate window ends at about 400°C temperature. Higher temperature tests were carried out for TMP- and PGW-based SC paper with grammages of 54 and 56 g/m^2. Paper rolls were produced on a full scale pilot machine and then dried on a pilot machine presented earlier in Figure 2. Initial dry content before the impingement unit was 50% on average. Paper was dried to dry contents between 91 and 99% indicating overdrying in some cases. Drying rates obtained by impingement drying with air temperatures up to 450°C are presented in **Figure 5**.

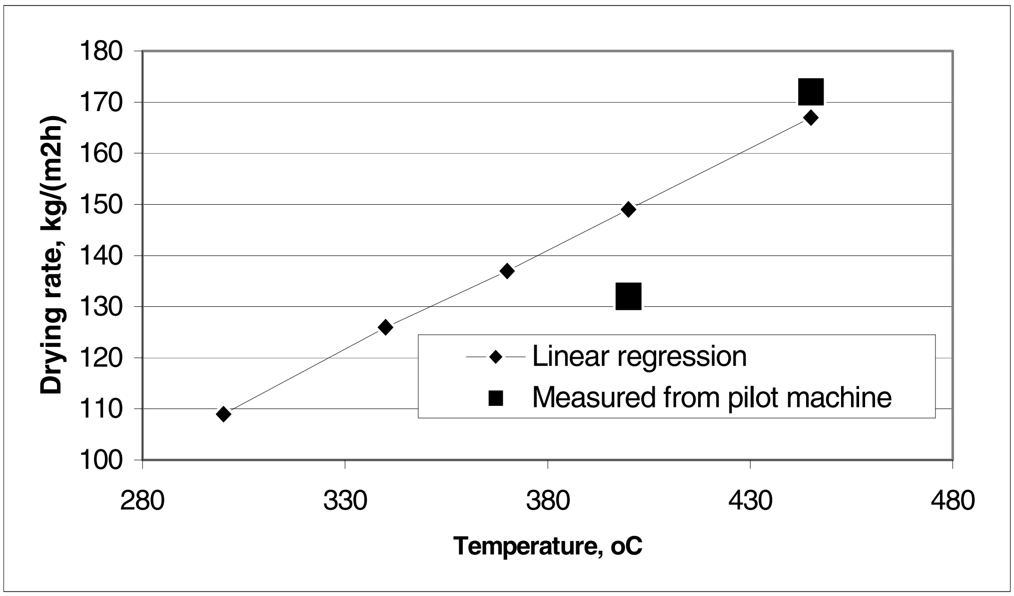

Figure 5. Drying rates for studied papers. Linear regression model from Kiiskinen /3/.

The figure above presents the relationship between temperature and drying rate. Linear regression model gives an estimate for drying rate in the constant drying rate period. The samples with measured values 132 kg/m^{2}h and 172 kg/m^{2}h were dried to moisture levels of 3.1% and 8.9%, respectively. Clearly, the value obtained at 400°C temperature is lower than the one obtained from the regression model. On the other hand, the measured value at temperature 445°C gives a higher drying rate than the regression model, although paper was dried to a 91.1% dryness. The difference, however, is not big.

Paper Quality

The following quality analysis was made on paper dried in a manner described previously:
- optical properties
- roughness
- rheological properties

In past years it has been noticed in several paper mills that paper brightness decreases when cylinder surface temperatures are too high at the beginning of the dryer section. This has created problems, especially with mechanical paper grades and the same problems were anticipated in impingement drying. In high temperature impingement trials, brightness values were measured from samples dried at a temperature of as high as 445°C. The results, shown in **Figure 6**, are somewhat surprising.

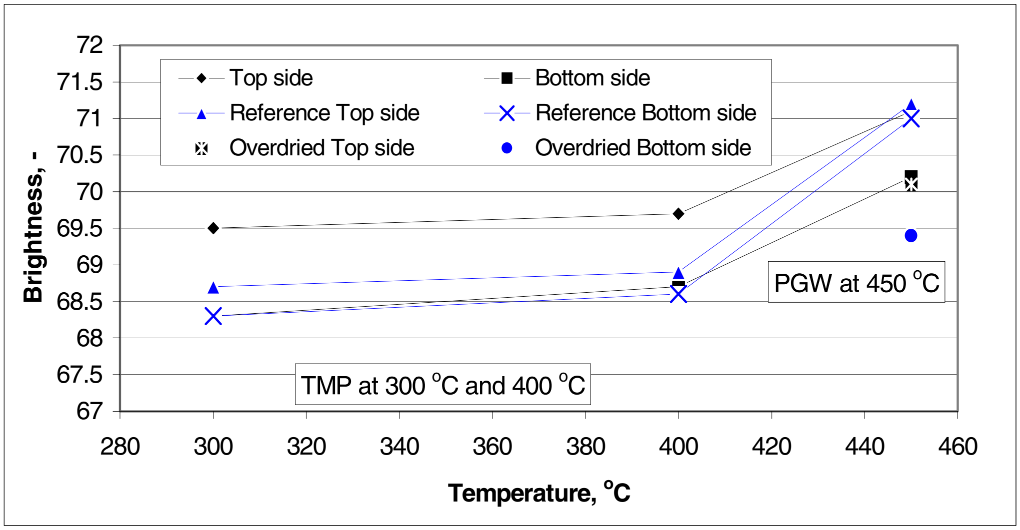

Figure 6. Brightness of paper samples dried at high temperature.

In that the impingement side (top side) brightness is one unit higher than the bottom side brightness. Reference papers, which were dried in laboratory (at room temperature), show same brightness values for both top and bottom sides. The lower brightness in this case can be due to the fact that paper is dried totally by one impingement unit and most of the drying happens on the impingement side (top side), while the bottom is at all times exposed to a hot, humid environment. The latter may affect changes in lignines and hemicelluloses. The same trend in brightness changes can be seen both for TMP-based and PGW-based papers, only the level is a little higher for PGW.

Opacity was also measured from the same samples dried with high temperature as can be seen in **Figure 7**.

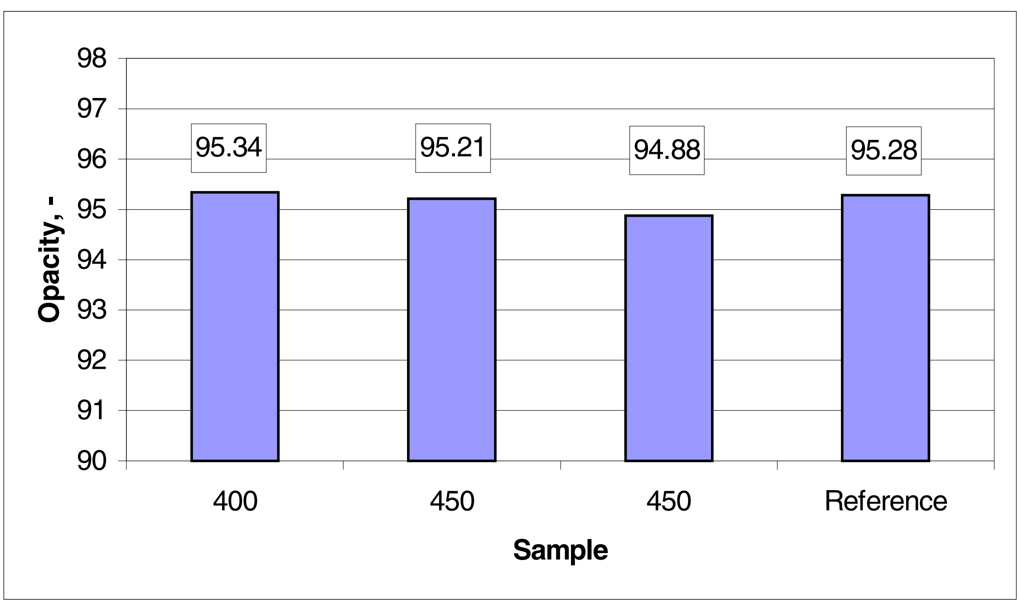

Figure 7. Opacity for impingement dried papers (SC-paper).

The two first columns are overdried samples at 1.8 and 1.5% moisture levels, respectively. The third column illustrates drying up to the final moisture content of 8.9%. Overdried samples seem to have slightly higher opacity than paper dried to higher moisture content. The reference point has the same opacity as in the overdried case, the "normally" dried sample having 0.4 units lower value than the reference point. However, differences are very small.

Paper roughness was also determined for paper dried in different conditions. It was noticed that impingement dried paper had lower roughness than reference paper dried in laboratory (conditioning room). No comparison with cylinder dried paper was made in this study. Laboratory (conditioning room) dried paper normally produces high values. It has been observed in other trials that impingement and cylinder drying produces approximately the same roughness.

In these trials the web was dried in an unrestrained condition, i.e. it was free to shrink since it ran on the vacuum roll surface without the presence of vacuum in the vacuum roll grooves. This means that it shrank freely on the fabric surface and was affected only by the drying intensity applied. Tensile and stretch properties were measured for both cross (CD) and machine directions (MD). Measured properties were: stretch at break, modulus of elasticity, tensile strength and tensile index. Only slight changes in rheological properties were noticed. Tensile strength in CD was found to be higher than the reference on all measured points except the one that was dried from moisture content of 48.6% to 40.3%. Stretch properties in CD were same for all test points.

MD-tensile strength increased when the impingement drying content was increased. The reason for this is that samples dried in a conditioning room in the laboratory are not under tension during drying while on the pilot paper machine they are constantly subjected to machine direction tension during drying. This leads to higher MD tensile strength and lower MD stretch. **Figure 8** shows the effect of drying on MD strain at break.

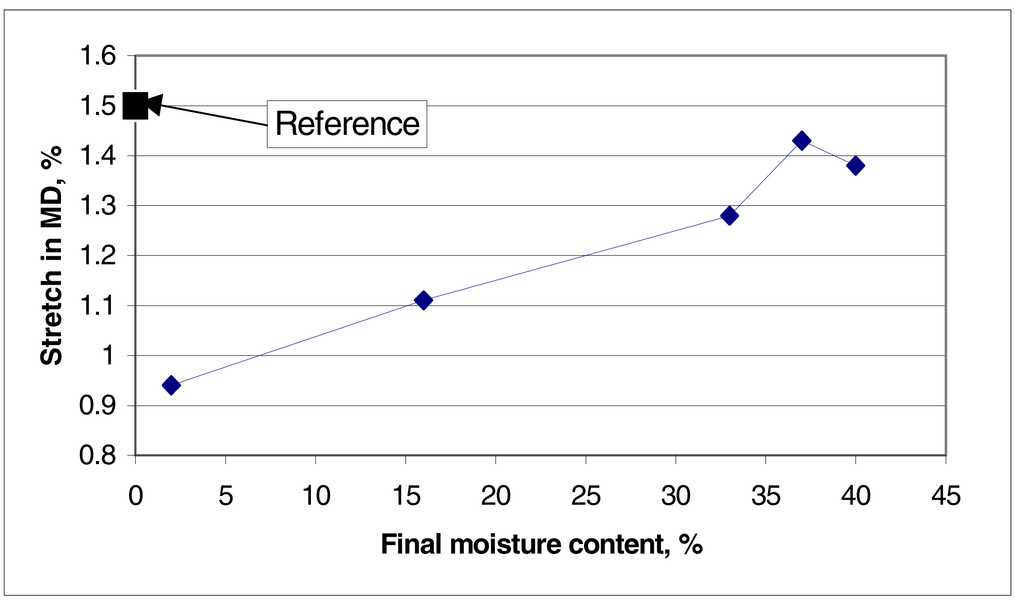

Figure 8. Stretch values in MD for impingement dried paper. Final moisture content means that paper is dried to that moisture with impingement drying. The rest of the drying is made in a conditioning room (no tension).

Paper Quality Compared to Conventional Cylinder Drying

The preceding chapter focused on the quality effects of impingement drying in comparison to laboratory drying. This chapter deals with the effects of impingement drying on paper quality as compared to cylinder drying. Comparisons were made by first drying paper using a pilot machine impingement unit (Figure 2) and then drying paper on the same pilot machine using only cylinders. The paper used was TMP-based uncalendered 45 g/m^2 grammage newsprint. The difference, or similarity in this case, in paper quality after drying can be seen in **Figure 9**.

Effects on Uncalendered News

		IMPINGEMENT DRYING	CYLINDER DRYING
DRYING RATE (kg/hm²)		61...141	15-25
POROSITY (ml/min)		447...525	398
ROUGHNESS (ml/min)	TS	862...1135	1251
	BS	968...1225	1183
TENSILE INDEX (Nm/g)	MD	67.4...74.5	70.9
	CD	17.3...21.7	16.0
MODULUS OF ELASTICITY (N/mm²)	MD	4855...5782	5755
	CD	833...1352	652
STRETCH AT BREAK	CD	1.56...2.56	3.46
BRIGHTNESS (%)		55.4...56.5	55.7
OPACITY (%)		86.6...87.8	87.3

Figure 9. Comparison between impingement and cylinder drying. Pilot machine experiments.

Based on Figure 9, we can conclude that impingement drying produces comparable quality paper as cylinder drying. There is a difference in CD stretch which is due to restrained drying when impingement drying is used. The differences in tensile index (CD) and CD modulus of elasticity also stem from restrained drying. Although the drying rate is much higher for impingement drying than for cylinder drying, there are no harmful effects on paper quality.

Paper quality was also studied on a production machine. Samples were taken from the reel after paper was dried with and without impingement drying. **Figure 10** presents MD and CD stretch and elastic modulus measurements and brightness and opacity values for paper dried with and without an impingement dryer.

The results presented in Figure 10 are based on production machine measurements when impingement drying is utilized only for a given short dry content area because the machine used only has one drying unit. Most of the drying is still accomplished through conventional cylinder drying, which accounts for the fact that no changes can be seen in the rheological or optical properties of paper.

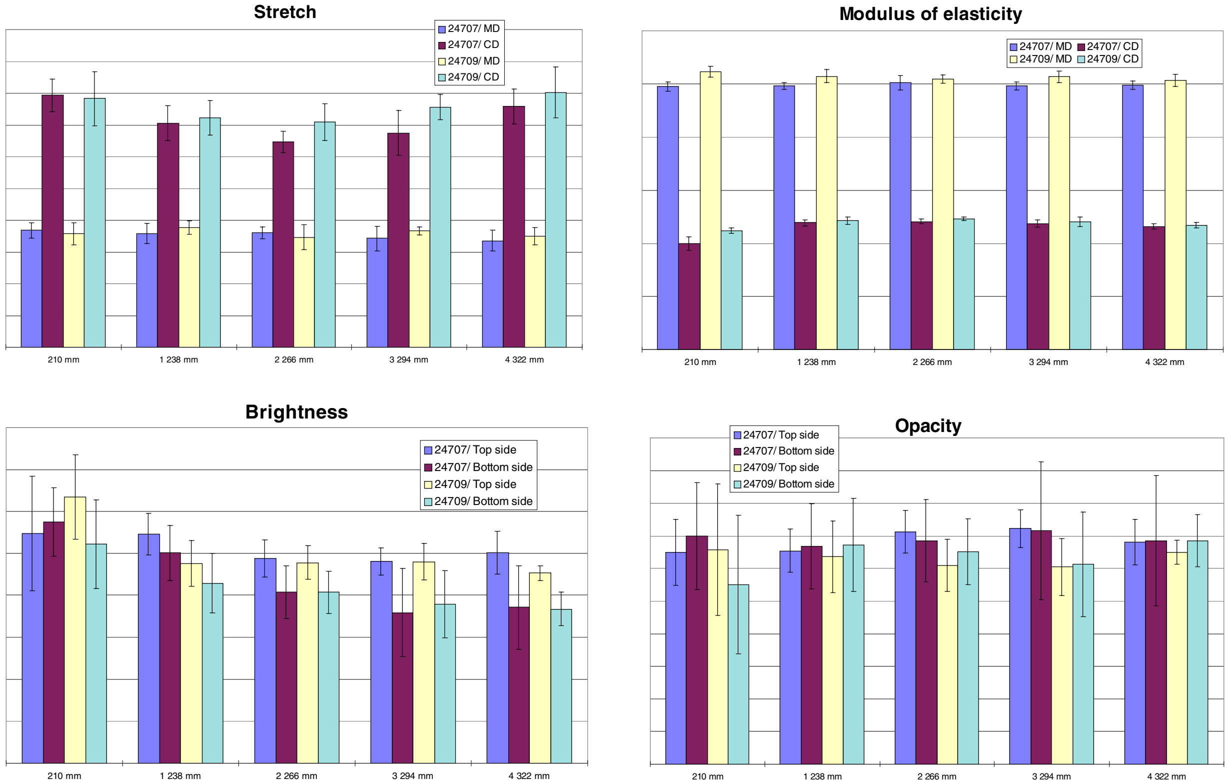

Figure 10. Comparison between impingement and cylinder drying. Production machine experiments. Reel 24709 is produced without impingement drying and reel number 24707 with impingement drying.

ENERGY SAVINGS WITH HIGHER IMPINGEMENT TEMPERATURE

In today's paper machines, most of the energy consumption takes place in the dryer section. The calculated energy consumption of impingement dryer section is at the same level as a cylinder dryer section since in both cases the same amount of moisture is evaporated. It is clear that finding ways of reducing energy costs will give added significance to the new drying techniques and concepts. The aim is to operate the impingement system with air recirculation and at an elevated humidity level. The energy consumption of an impingement drying system is directly related to the impingement air humidity level. Higher air humidity also results in a slightly lower specific drying rate.

Higher impingement temperatures lead to higher gas consumption, but with maintained nozzle velocity the electrical energy consumed by the fan motors is greatly reduced. Since the electrical energy in most cases is the more expensive energy, the specific energy cost decreases with increased temperature. The general relationship between these parameters is presented in **Table 1**.

Parameter	Evaporation	Specific energy cost
Increased jet velocity	+	-
Increased jet temperature	+	+
Increased air humidity	-	+

Table 1. Overall effect of drying parameters. (+ = Favorable, - = Negative)

As can be seen from the table above the increased impingement temperature gives savings in energy costs in addition to the higher evaporation rate.

FABRICS USED IN IMPINGEMENT DRYING

Impingement drying utilizes very hot air to dry paper. This means that fabric tolerance to temperature is an important issue, since the fabric supports the web all the time during drying. As long as the moist paper is on the fabric surface there is no danger of fabric damage, since the web temperature remains well below 100^{o}C. This condition in fact holds true for the entire fabric width, except at the edges where the fabric is directly exposed to up 450^{o}C blast of air. Width of the produced paper also changes from grade to grade which means that the fabric has to be in some way protected at the edges.

Before commercializing the impingement dryer, a study was made to determine the relationship between the impingement drying width and corresponding paper width. The result showed that the air jet spread at point of impingement such that the paper could be somewhat wider than impingement area and still be adequately dried at the edges. This led to the solution of an impingement hood with adjustable blowing width at the edges. In this way the fabric is protected against hot air at the edges even though paper width is changing every now and then. The NP1 impingement unit has this kind of control system, which works very well. Fabric edge temperature stays below 130^{o}C even though the impingement air temperature has been 350^{o}C.

The fabric is also fully protected in case of a web break. This is accomplished by rapid retraction of the hoods prompted by a signal from break detecting sensors. Such an automatic retraction system has worked very reliably at NP1 and no fabric damage has occurred due to direct impingement of hot air.

SUMMARY

Impingement drying has been studied with different pilot machines for many years. All main paper grades have been tested on either a separate pilot drying unit or with an on-line pilot drying unit that is a part of a full scale pilot machine. Drying efficiency for different paper grades has been studied and was found to be about the same for newsprint, fine, LWC base paper and SC-paper in the same paper moisture and drying conditions.

The studies have shown that impingement drying temperatures of up to 450°C can be used for printing paper grades. The possibility to use such high temperatures is due to the fact that the temperature in the paper web does not rise above 80 to 90°C. This temperature range is generally valid when paper moisture stays above 15%. In conventional cylinder drying, the paper web undergoes periods of high temperature rise at low evaporation, when it is sandwiched between a hot dryer surface and fabric and periods of rapid evaporation and cooling during the free draw between consecutive cylinders. In impingement drying evaporation occurs continuously, which keeps paper temperatures low.

Quality aspects have been an important issue in impingement drying. In this study, some SC-paper quality aspects were dealt with. Changes in optical and rheological properties were found to be small. In addition, roughness values did not change much, when more impingement drying was used (drying different moisture areas with impingement drying). In the light of this study, there is no reasons why high impingement air temperatures could not be used for all other printing papers. High temperature also improves drying efficiency and reduces energy costs.

The first commercial impingement dryer installation continues to work well. Drying efficiency has been as expected and runnability has been excellent. Impingement drying has proved to be equally effective for both lighter and heavier paper grades (at NP1 from 110 g/m^2 to 250 g/m^2). No quality changes have been observed from conventional dried paper.

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