"Controlled Overdrying: Effects on Some Physical Properties of Fine Paper"

John T. Collins

Western Michigan University

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"CONTROLLED OVERDRYING: EFFECTS ON SOME PHYSICAL PROPERTIES OF FINE PAPER"

by
John T. Collins

A Thesis Submitted To The Faculty of the Department of Paper Science and Engineering In Partial Fulfillment of the Degree of Bachelor of Science

Western Michigan University Kalamazoo, Michigan

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ABSTRACT

The purpose of this study was to determine the effects of certain drying variables on some physical strength properties when these variables were controlled to bring about overdrying conditions. The variables under study were contact time on the dryer can (% moisture) and different percentage hardwood-softwood compositions. From the study it was discovered that overdrying actually increases tensile values but mullen and tear values did indeed decrease.

The object of the following report was to see if there was a decrease, if any, in certain physical properties and to what degree. If overdrying a sheet actually decreases the physical properties by a very small amount the following is proposed. If one can add an extra wet press roll on the same wet felt with a suction box in between press rolls a higher consistency could be obtained when entering the first dryer section. With a higher consistency going into the first dryer section (of approximately 5-10%), the amount of water to be removed would be substantially decreased. With this increase in consistency the sheet could be subjected to overdried conditions. With the sheet in an overdried state the last two dryer cans could be run as cold rolls. These cold rolls would then bring the sheet's moisture content back to a desired state (depending of course on customer order). The initial cost of the extra wet press roll could be paid for with the energy savings obtained by running the two dryer cans steamless. Therefore, if a sheet could be overdried (without sacrificing production) and then rewetted with minimal fluctuations in physical properties an economical benefit would result.

The following is a study to see if indeed this idea could be put into practice. The results were then related to tensile, tear and mullen in an attempt to establish a relationship of overdrying to these physical characteristics. The tensile, tear and mullen were all run according to respective Tappi Standards.
INTRODUCTION

It is a well known fact that cellulose fibers exhibit many physical changes during the drying process. The degree and severity of drying can influence the amount of effect the individual physical changes of fibers can have on the entire sheet structure. Drying is dependent upon the length of time and degree of temperature to which the fibers are subjected.

In commercial practice on many paper machines equipped with size presses, it is not uncommon to overdry the sheet to some degree before the sheet enters the size press. Operators may do this knowingly because it helps in building a better reel by minimizing problems with moisture profile, or it may happen unknowingly because there is no moisture sensing equipment before the size press and it is easier to play it safe and avoid the risk of running wet. In either case, overdrying is generally regarded by technical people as a poor practice because of adverse effects on strength properties. However, it is not clear that a moderate amount of overdrying has a significant adverse effect and it can be postulated that the property of dimensional stability might actually be improved with little sacrifice in other properties. This increase in dimensional stability could result in a net benefit for grades such as those used in multi-color offset press work where dimensional stability is important to register.

It was the purpose of this thesis to review drying theory, review literature reports on the effects of variables upon which degree of drying are dependent, and to experimentally analyze some selected variable effects upon certain physical characteristics of a sheet.
LITERATURE REVIEW

Drying Theory

During the drying of a sheet of paper certain intricate processes occur that cause the moisture in the sheet to move from the interior of the sheet to the surface where it is vaporized. Therefore, a basic understanding of these processes will help apply the drying theory to the problem of overdrying the sheet.

A discussion of the drying theory must inevitably begin with the presentation of a typical drying curve. Such a curve is shown in Figure 1. Although a drying curve like this has been accepted for many years, not all aspects of it are completely understood.

During the drying of a virgin sheet of paper, there is a normal sequence of events which occurs. Figure 1 profiles four definite stages in this sequence. In the first stage, from A to B, the paper surface is covered with water and the rate of evaporation is constant. From B to C the evaporation drops at a rate determined by the various factors controlling the flow of water to the surface. At C there is a transition point indicating that absorbed and capillary water begins to evaporate. Since this water has a lower vapor pressure, the rate of evaporation will drop further. At D, only bound or hydrated water remains, and this water is bound to the cellulose and the hemicellulose molecules or absorbed on them as a monomolecular layer. The bound water may amount to nearly one percent, and of course, should never be removed during the paper drying. Subsequent layers of water molecules make up the absorbed water which is characterized by a higher density, a lower vapor pressure, and a higher specific heat than free water. Water in small capillaries will also have a lower vapor pressure. As indicated in Figure 2, the degree of orientation of the water molecules drops from layer to layer until, at about 17 per cent moisture content, a density of 1.0 is reached (2), (3), (4).
Fig 1: Typical Drying Curve for Paper
A-B = Constant rate of drying
B = Surface film broken
C = Absorbed Water Evaporating
D = Hydrated Water Evaporating
Some knowledge of this absorbed water is useful, since part of the absorbed water must be removed during the drying process.

It appears that the amount of absorbed water varies with hemicellulose content and degree of beating. Hemicellulose contains a larger percentage of hydroxyl groups than does cellulose and therefore absorbs more water. Because of this fact, groundwood pulp holds more absorbed water than a chemical pulp. This can be illustrated by the higher moisture content of pulp at a given air humidity (adsorption) as demonstrated in the following data (5).

A. Groundwood pulp - 10% at 65% R.H.
B. Sulphite pulp - 8.8% at 65% R.H. (unbleached)
C. Sulphite pulp - 8.4% at 65% R.H. (bleached)

Beating disintegrates part of the primary wall and the outer secondary wall, permitting water to penetrate into the inner secondary wall. A saturated fiber wall will hold about 30 per cent water. Water is also absorbed by the fines produced during grinding and beating.

To remove absorbed water from a sheet of paper, the heat of desorption has to be added to the heat of evaporation of free water. Figure 3 shows how this will affect the amount of heat needed to dry paper of 45 and 50 per cent dryness to various final dryness levels. This figure also indicates 17 per cent absorbed water (1).

When a sheet of paper has been saturated with absorbed water, capillaries and lumens then begin to fill. At the saturation point, a pulp suspension contains two milliliters of water per gram of fiber, or about as much water as a piece of wood holds (5).

This raises a question concerning the void fraction in paper. Figure 4 shows the pore size distribution in air-dried and freeze-dried handsheets of sulphite pulp. In both cases, maximum pore volume occurred
Fig 2: Average Density of H₂O Remaining in Paper At A Given Moisture Content
at one to two microns pore radius. Freeze-drying made the sheet bulkier
but did not materially alter its pore size distribution. This is under-
standable if one assumes that paper is composed of a number of fibrous
networks. Wet pressing had little effect on the void fraction, indi-
cating that the pressing process did not cause bonding. The void
fraction of air-dried sheets was found to be about 20 per cent, although
most of the lumens had collapsed (6).

During drying, the free water in the lumens and other voids of
the paper is evaporated, (Stage B-C, Figure 1). This leads to the
partial collapse of the voids and to the bonding of the internal sur-
face, a reaction which is not easily reversed. Further evaporation
of absorbed water causes the fines and fibrils to adhere to the fiber
surfaces. Finally, the water in the fiber walls is desorbed followed
by a shrinkage of these walls (1).

During the first stages of drying, the fibers are free to slide
on each other, there is no bonding yet, and thus, there can be but a little
tension in the sheet. As the free water is driven off, the stage where
the hydrated water starts to evaporate begins. At this point, bonding
between fibers starts to take place, and from this point the greater
part of shrinkage takes place. During this bonding period, any un-
equal tension which is set up in the sheet will result in curl and
cockle at the reel. At this point there are two opposing factors which
are fighting against each other. On the one hand, the fibers are trying
to shrink as they lose moisture and this shrinkage tends to produce a
definite tension in the sheet. On the other hand, the hydrated cellu-
lose is trying to set, thus bonding those fibers so they cannot shrink,
and this tends to add more tension to the sheet. Naturally, high
temperatures and rapid drying at this critical point only tends to
aggravate the condition. Any fiber whether it is leather, wood, wool,
or paper is injured by excessive temperature and the result is an
excessive shrinkage, warping, and hardening of the fibers. Lumber
Fig 3: Effect of Heat of Desorption on Average Heat of Evaporation As a Function of Final Dryness
Fig 4: Pore Size Distribution for Air Dried And Freeze Dried Paper
which has been allowed to slowly air dry in the shade, is far superior to the commercial lumber which is dried at higher temperatures. Yet most paper machines today apply full steam temperatures to the dry end thus causing excessive shrinkage, cockling, and at the same time injuring the bonds which tends to reduce the strength (7).

If the fact has been established that low temperatures will not harm any of the papermaking fibers and that high temperatures will injure them, then why is it that papermakers use the high temperatures? Papermakers, and even nature, have conspired to change matters so that the higher temperatures are actually necessary. Although the high temperatures are detrimental to the actual strength of the fibers, enough strength is gained from other things to more than offset the loss of fiber strength. For examples, the great majority of papers contain rosin or resinous material (lignin). Either the papermaker adds it, or as in the case of groundwood and most pulps, nature has already added it.

It has been experimentally found that when resinous material is present with the papermaking fibers, it is necessary to heat the paper in the process of drying, to such a temperature (approximately 279°F) that will flux or sinter the resinous material. As in the case of rosin, addition of this material must take place before formation on the wire. This material will then flow and bind the fibers into a compact mass giving the resulting paper greater strength than it would of had without the necessary temperature, and addition of the rosin before formation on the wire. Further, this sintering of the resinous material will impart what is known as sizing to the paper (8).

Profile and Density Variations

When drying paper, a variation in moisture content of paper across the width of the machine and several related problems may arise.

Research has been directed primarily toward seeking the cause of moisture profile variation and the means to eliminate it, but little has been done to find out why it is a problem. To be sure, newsprint manufacturers can see a direct major profit improvement in raising the average moisture level of the shipped papers, and others believe minor gains
in operating efficiency will be obtained. Many mill officials have taken the view if the small moisture peak on the reel moisture profile could be eliminated, their worries would be over. There is substantial reason to believe this viewpoint is in most cases erroneous. While the effects on quality are rarely documented (no one wants to demonstrate quality deficiency), sufficient basic information is available to challenge the concept that uniform moisture profile alone is a valid objective. If this concept were true, the simplest solution would be to dry almost all the water out of the sheet and then remoisten it uniformly. This is done to some extent on all paper, but serious quality problems remain (9).

The basic lesson in moisture profiles is that variation in moisture profile in practice requires gross overdrying of the sheet in part or in whole. The question of the definition of the term overdry immediately arises. The word itself implies drying beyond the required point of dryness, but as applied to paper it has further meaning. Jentzen (10) found that mechanical properties of pulp fiber were affected by drying under tension and further, that there was no difference in mechanical properties between never dried and once dried, rewet fibers. It is critical to note that Jentzen dried the fibers slowly in an air atmosphere at 73 degrees F and 50 per cent R.H.. Such fiber could not be considered overdried, and its condition with respect to mechanical properties at least was reversible. On the other hand, other investigators (11-15) have shown that fibers dried beyond a certain point and at elevated temperatures undergo irreversible changes in their properties. The most notable of these is the shrinkage of the fiber with loss in its ability to resorb water. The permanent loss in absorbptivity apparently increases with increased drying temperatures. Equally important is the permanent major loss in fiber strength which decreases greatly and continuously with the period of treatment at high temperature. One hypothesis explaining the loss in strength is that the cellu-
lose becomes depolymerized and the fiber embrittled. Continuing re-
search in fiber structure will undoubtedly reveal more details of these
and other properties as they are affected by excess heat. The common
characteristic of these properties is that they are irreversible. It
is suggested that when fibers enter the state where their physical pro-
properties (elongation for example) are irreversibly changed, which results
from extreme heat and dehydration of the fiber, the fibers are then
overdried.

Overdrying as applied to the web on a paper machine is not direc-
tionally uniform, nor is it locally uniform. Typical moisture profiles
clearly demonstrate that the extent or severity of drying progressively
increases from a peak usually near center toward both edges of the web
(see Figures 5 and 6). There are several variants of this condition
caused primarily by efforts of the operators to level the profile. At
the risk of wrinkling the web, operators often load the wet presses to
one side or near the center, to dry up the profile peak. They frequently
make small adjustments in basis weight across the machine. It is almost
standard practice to raise the basis weight at the edges, which produces
the slight rise at the edges in typical profiles. These and other strat-
agems usually succeed in making the amount of cross machine variation more
tolerable, but they also mask the configuration and degree of variation (9).

There exists a tendency for the surface fibers on a web to overdry
more than the interior fibers. Han and Ulman (16) showed that steep temp-
erature gradients develop at the hot surface in hot surface drying of thick
fibrous mats. The conditions that exist on a paper machine as the paper is
overdried are much more extreme than in their tests. The actual drying
process is several times faster and the amount of overdrying is greater.
The surface temperatures of the driers are raised, for reasons of higher
production, to a range of about 260-280 degrees F in comparison to the 190
degree F temperature used by Han and Ulman (16).
Fig 5: Typical Moisture Profiles for a Newsprint Machine

Fig 6: Typical Reel Moisture Profile for Sizoo Book Paper
If paper was of homogenous construction, no variation in localized drying could be inferred. This factor is not so, because the fiber density varies locally in most paper, depending primarily on the formation characteristics of the paper machine. When passing through the high nip pressures of the wet presses, the more dense spots are compacted to a greater degree than the surrounding fibers, although a slight increase in wet caliper remains. The idea that paper on multicylinder drier sections does not lie in direct contact with cylinder surfaces at all times is generally accepted. There usually exists a very small air gap between the paper and cylinder surface. At the dense spots in the paper, the increased caliper greatly reduces or completely bridges the air gap, which results in a higher degree of heat transfer at those points. Upon the excess drying of the web, both the surface and interior fibers of these spots are overdried to a higher degree because of the higher rate of heat transfer created within the more dense material. Because of these facts it can be stated that overdrying accentuates the variations resulting from poor formation.

Not much work has been reported in the way of relating moisture profile and the resultant overdrying with specific quality deficiencies.

It would seem that the mechanical properties would be the most affected. Zero span tensile strength reflecting fiber strength most directly, is seriously affected. The 4 in. tensile span strength, as reported by Britt and Yiannos (15) is also affected, although not greatly. It would then seem that the damage of overdrying would be restricted to the fiber itself instead of the interfiber bonds. The embrittlement of the fiber, caused by overdrying, also causes loss in web stretchability. Such occurrences as cracking upon folding could probably be traced to the embrittlement of the fiber, along with the adverse affects to other mechanical properties such as resiliency.

Dimensionally stable paper is essential in many processes and most es-
especially printing. Uniformly overdried and reconditioned paper might behave well, but because of moisture profile variation, some elements of the width of the reel are greatly overdried in comparison to others. An extreme variation in degree of overdrying can also exist across the width of rolls trimmed and rewound for shipping. The dormant strains are released upon exposure to press room humidity and cause havoc on the press. Wrinkling, misregister, and even poor tracking of the web are typical for such rolls. Depending on how long the roll is stored and on the atmospheric conditions of storage, the characteristics of the roll may be changed during the press run. In the case of multi-color web offset presses, the web is even more difficult to handle because of moistening at each printing. Curl is another dimensional difficulty that is likely to be affected by overdrying. Moist paper has less tendency to curl than dry paper. The further paper is dried, the more likely that inherent strain will be built in. Overdried paper may be reconditioned to lay flat at higher moisture contents only to develop curl at a later date. Cockling, which results from the building of localized strains by overdrying, may also show up when the overdried paper would be remoistened (9).
EXPERIMENTAL DESIGN

To evaluate some of the effects that overdrying has on some of the physical properties of paper while controlling composition and freeness the following experiment was conducted.

The relationship between some strength properties of paper and the varying compositions of the paper being exposed to different drying conditions was studied.

Three different compositions were used with the following makeups; 50% hardwood-50% softwood, 60% hardwood-40% softwood, 60% softwood-40% hardwood. The hardwood used was Weyerhaeuser hardwood while the softwood was Rayonier softwood. All three mixtures were refined and beaten in the Valley beater at 36 amps with distilled water. The three compositions were beaten to a Canadian Standard Freeness of 383 for the 50% H-50% S, 373 for the 40% H-60% S and 379 for the 60% H-40% S. The pH reading was 7. The three furnishes were selected to detect if there was indeed any abnormalities in the observed physical properties from one furnish to another, with different drying conditions prevailing.

Handsheets were formed on the Noble and Wood Sheet Machine and conditioned for at least 24 hours in the laboratory constant humidity room at a temperature of 73°F and 60% relative humidity. The handsheets produced all weighed approximately 2.5 grams±0.1 grams.

To simulate the passage of the sheet through a dryer section, the sheets were subjected to a range of overdrying conditions. With the temperature being held constant at 240°F only the contact time was varied on the dryer can. The contact times were varied from 44 sec. to 255 sec. with moisture being controlled by weighing the sheet at 44 sec. intervals. This latter process was exercised in order to establish a moisture content curve. This helped to establish a meaningful relationship between the furnishes and their moisture contents as related to their
respective physical properties. Four moistures were used for each composition. The four being 12%, 8%, 2%, and 0% moisture for each composition. All compositions were wet pressed at constant and identical pressure.

The sheets were then conditioned in the constant humidity room to allow them to reach an equilibrium. After equilibrium was attained a series of tests were conducted on the Instron Tensile Tester, Mullen Tester and Elmendorf Tear Tester. Mullen tests were run according to Tappi Standard T403, tensile tests according to T404 and tear test according to T407.
DATA DISCUSSION

An examination of the tensile vs. % moisture graph reveals that at overdry conditions the highest values are obtained. The lowest values for tensile are located at the 2% moisture levels for all three furnishes. As one can see the tensile drops at the 2% moisture level and then rises for each composition. This could be caused from the H-bonding between fibers and fiber networks. The 60%S-40%H value being the highest (at overdry conditions) indicates that the length of the fiber and the percentage of that fiber in the furnish will indeed be a function of the tensile values at the overdry condition. It seems that the overdried sheet tends to reabsorb water more readily than a sheet with moisture contained within it already.

At the 2% levels all furnishes seem to be at a low which is evidence of the afore mentioned. All three furnishes seem to more or less level off at the higher moisture contents but still being lower in value than overdry conditions. The higher moisture levels of course are losing water during the retention period in the constant humidity room. The tear vs. % moisture graph on the other hand seem to be a bit erratic. All furnishes have their high values at the high moisture levels. The 60%S-40%H has a type of sinusoidal curve. It is clear to see that overdried conditions for all three furnishes does not facilitate tear values.

Turning to the Mullen vs. % moisture graph, the overdried conditions do not seem to increase the Burst factor as such. All three furnishes have the same shape as far as curves. The 60%S-40%H is once again the highest at all moisture levels as compared to the other two furnishes. The 2% and 12% moisture levels seem to be the most optimum moisture levels to run a given furnish if high Mullen values are desired.

If the same study was carried out with fiber orientation controlled to produce initially high physical characteristics, the loss caused
through overdrying would probably yield a value practical and acceptable for production of paper by the controlled overdrying method.

Even though the physical strength loss does correlate with the theory stated in the literature, it would be an adverse affect only if strength dropped below acceptable industry standards.

The data on the following pages are averages for a given number of trials. These averages were tested for differences (significant or not significant) through the application of the "Difference of Two Means t-test". The following are the results of these t-tests:

For Tensile- 9% moisture level, 50%H-50%S is significantly different from both 40%H-60%S and 60%H-40%S.
- 8% moisture level, 50%H-50%S is significantly different from both 40%H-60%S and 60%H-40%S.
- 12% moisture level, 50%H-50%S is significantly different from 60%H-40%S.

For Tear- 9% moisture level, 50%H-50%S is significantly different from both 60%H-40%S and 40%H-60%S.
- 2% moisture level, 50%S-50%H is significantly different from both 60%H-40%S and 40%H-60%S.
- 8% moisture level, all three compositions are significantly different from each other.
- 12% moisture level, all three compositions are significantly different from each other.

For Burst- 9% moisture level, 50%H-50%S is significantly different from both 60%H-40%S and 40%H-60%S.
- 2% moisture level, 50%H-50%S is significantly different from both 60%H-40%S and 40%H-60%S.
- 8% moisture level, 50%H-50%S is significantly different from both 60%H-40%S and 40%H-60%S. The t-test value obtained was slightly different from the table value (1.321 - 1.311 = 0.01). This difference is obviously a slight difference.
- 12% moisture level, 50%H-50%S is significantly different from both 60%H-40%S and 40%H-60%S.

NOTE: The above analysis only mentions the significantly different means. Any paired mean not mentioned (or compared) above is not significantly different. In other words $H_0: \mu_1 = \mu_2$ is the acceptable hypothesis.

For significantly different means the acceptable hypothesis would be $H_1: \mu_1 \neq \mu_2$. Procedure for t-test analysis can be found on page 19.
TENSILE TEST  
(kg-force)

<table>
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<th>Compositions 50%H-50%S</th>
<th>Compositions 40%H-60%S</th>
<th>Compositions 60%H-40%S</th>
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</thead>
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<tr>
<td>12%</td>
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<td>10.4</td>
<td>8.37</td>
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<tr>
<td>8%</td>
<td>8.34</td>
<td>10.28</td>
<td>8.35</td>
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<tr>
<td>2%</td>
<td>7.23</td>
<td>8.00</td>
<td>7.55</td>
</tr>
<tr>
<td>0%</td>
<td>9.21</td>
<td>11.06</td>
<td>9.18</td>
</tr>
</tbody>
</table>

\[ t - test: \]

1. \( H_0: \mu_1 = \mu_2 \)
2. \( H_1: \mu_1 \neq \mu_2 \)
3. \( \alpha = .10 \)
4. \[ s_{x,y} = \sqrt{\frac{1}{n} \sum_{i=1}^{b} (x_i, y_i) - (\bar{x}, \bar{y})^2} \]
5. \[ s' = \sqrt{n} \ast \sqrt{s_x^2 + s_y^2} \]
6. \[ t_{.10} = \frac{\bar{x} - \bar{y}}{s'} \sqrt{n - 1} \]
Tensile vs. % Moisture

Graph showing tensile strength (Kg-fence) vs. % moisture.

- 50% Hardwood - 50% Softwood
- 40% Hardwood - 60% Softwood
- 60% Hardwood - 40% Softwood
<table>
<thead>
<tr>
<th>Moisture</th>
<th>Composition 50%H-50%S</th>
<th>Composition 40%H-60%S</th>
<th>Composition 60%H-40%S</th>
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<tr>
<td>12%</td>
<td>36.37</td>
<td>51.2</td>
<td>44.06</td>
</tr>
<tr>
<td>8%</td>
<td>36.37</td>
<td>46.10</td>
<td>30.10</td>
</tr>
<tr>
<td>2%</td>
<td>34.33</td>
<td>48.0</td>
<td>33.17</td>
</tr>
<tr>
<td>0%</td>
<td>33.61</td>
<td>43.41</td>
<td>35.68</td>
</tr>
</tbody>
</table>
Tear vs. % Moisture

- 50% Hardwood - 50% Softwood
- 40% Hardwood - 60% Softwood
- 60% Hardwood - 40% Softwood
<table>
<thead>
<tr>
<th>Moisture</th>
<th>50%H-50%S</th>
<th>Composition</th>
<th>60%H-40%S</th>
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<tbody>
<tr>
<td>12%</td>
<td>39.82</td>
<td>51.43</td>
<td>38.63</td>
</tr>
<tr>
<td>8%</td>
<td>28.64</td>
<td>38.13</td>
<td>27.91</td>
</tr>
<tr>
<td>2%</td>
<td>30.83</td>
<td>45.52</td>
<td>29.89</td>
</tr>
<tr>
<td>0%</td>
<td>30.26</td>
<td>40.34</td>
<td>26.97</td>
</tr>
</tbody>
</table>
Mullen vs. % Moisture

- 50% Hardwood - 50% Softwood
- 40% Hardwood - 60% Softwood
- 60% Hardwood - 40% Softwood
CONCLUSION

Although overdrying actually increases tensile strength for the three different furnishes the complications that would arise from the tear and mullen losses would render this practice economically unfeasible. If a customer would and could overlook the decreases (although not great) in tear and mullen then this idea would indeed save a substantial amount of money for a company. An idea that does come to mind is the process of dual rewetting conditions. This would be done by overdrying the sheet twice and rewetting twice. This could also have an adverse effect because of the extreme physical treatment of the sheet.

From the practical standpoint there has to be a compromise between the physical properties needed to run the sheet, say on a printing press, and the dimensional stability. Overdrying seems to throw this balance to the negative side, yielding a good stable sheet but one that will not run economically. The ultimate combination would be a sheet that would only change slightly in dimension and with no loss in physical strength.

From the above information, it seems that drying conditions to which the sheet is subjected holds the key to many of the problems encountered in production today. Theoretically, there is a certain and exact temperature at which a sheet of paper should be dried to attain optimum values for physical properties. It is understood that it may be rather hard to find just what this temperature should be for the drying conditions in which adverse effects will result.
RECOMMENDATIONS

Since this study was carried out using contact type drying techniques it would be interesting to study the effects of infrared on microwave type drying techniques to see if the same results would prevail.

Another area that could be explored is the fiber orientation. By determining the actual effect of fiber orientation a correlation could be made to dimensional stability along with physical strength. By drying a small portion of fibers and then examining the sheet under a microscope, orientation could be established. To get varying orientation profiles, machine variables such as headbox consistency, vacuum at flat boxes or shake could be altered to give different formation.


