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# The Effect of Dryer Fabric Tension on the Moisture Removal in Paper

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by

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# ABSTRACT

The efficiency of the dryer sections is becoming increasingly important as energy prices soar. In an attempt to evaluate one of the possible variables which influence the efficiency of the dryer sections, this study of dryer fabric tension was made.

Previous studies have shown that increased tension improves the heat transfer from the cylinder to the sheet by dissipating the insulating layer of air which separates the two. The tension necessary for this to occur was labeled the optimum tension. Tensions above the optimum gave no added benefits.

To test this hypothesis, three sets of trials were made on the pilot plant machine at Western Michigan University. The first set was made by varying the tension of the dryer fabric in the first dryer section. The second was made by varying the tension in the second, and the third by varying the fabric tension in both of the sections. Percent moistures were calculated and used to compare the percent moistures removed at the different tension levels. It was shown that when the tension is increased from near zero up to the optimum, the percent of the imcoming moisture removed increased by up to 6% for the pilot plant machine. The increases came nearly all from the first section while changes in the second dryer section showed very little effect. The study also showed that running at tensions above optimum decreases the percent moisture removed.

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## INTRODUCTION

In the past decade the rapidly rising cost of energy has forced the paper industry to look for new methods of energy conservation. In its attempt to reduce energy consumption, the industry has turned much of its attention to the dry end of the paper machine. The mechanism of the drying process, which has previously been considered of secondary importance, is now under close scrutinization as attempts are made to optimize dryer performance. The numerous variables which are involved in the drying process include:

1) length of time the paper contacts the dryer per cycle
2) length of time the paper is clear of the dryer
3) number of drying cycles
4) temperature of the dryers
5) pressure of the sheet on the dryer
6) pressure of the felt on the sheet
7) condition of the air in the pockets
8) velocity of the air in the pockets
9) type of sheet being dried
10) type of felt being used
11) sheet tension

Of these variables, the one most easily manipulated by the the machine operator is the tension of the felt against the paper web. The beneficial effect of increased felt tension is well known throughout the industry and its use is a common practice, but the extent to which the drying capacity can be increased and how to optimize the effect of felt

tension is not known. This paper will hopefully shed some light on the subject and in doing so should help papermakers to more effectively use this simple adjustment to increase the drying capacity of their paper machines.

## OVERVIEW OF DRYING

In order to understand how increasing the felt tension can increase the drying rate, it is first necessary to understand exactly what happens when a wet web of paper is dried. The mechanism of drying will be looked at three different ways: first as an overview of the whole dry end, secondly on a smaller scale looking at an individual dryer cycle, and finally by looking at the internal structure of the paper web.

### The Three Zones of Drying

When looking at the dry end of the paper machine there are three distinct zones through which the wet sheet passes. They are the warming up zone, the constant rate zone, and the falling rate zone.

The first zone consists of the first several dryers immediately after the press section. It is in this zone that the sheet begins to be heated. As the web enters this section its temperature slowly rises, but it is never sufficiently hot for there to be any water removed in the form of steam. In his studies Janett (1) found that because of the lack of vaporization there are only two possible mechanisms for water removal. When the sheet releases from the dryer surface there is a film splitting effect which leaves a thin layer of water on the dryer. As the dryer enters the pocket this layer is evaporated, but the amount

which is removed in this way is relatively small. The main mechanism for water removal in this section must then be that of capillary penetration of water from the web into the dryer felt (1). As the sheet is heated, it reaches a point where the water at the dryer-paper interface begins to vaporize. It is at this point that the sheet is considered to be in the constant rate zone.

Testing by Sherwood (2) and later by Gilland (3) showed that the main feature of the constant rate zone is the evaporization of water from a saturated surface. This evaporization of water from the sheet becomes the overriding factor in water removal replacing the capillary action. The drying rate through this zone remains fairly constant until enough water is removed so that the sheet can no longer maintain a continuous layer of water on the surface. This condition signals the start of the falling rate zone.

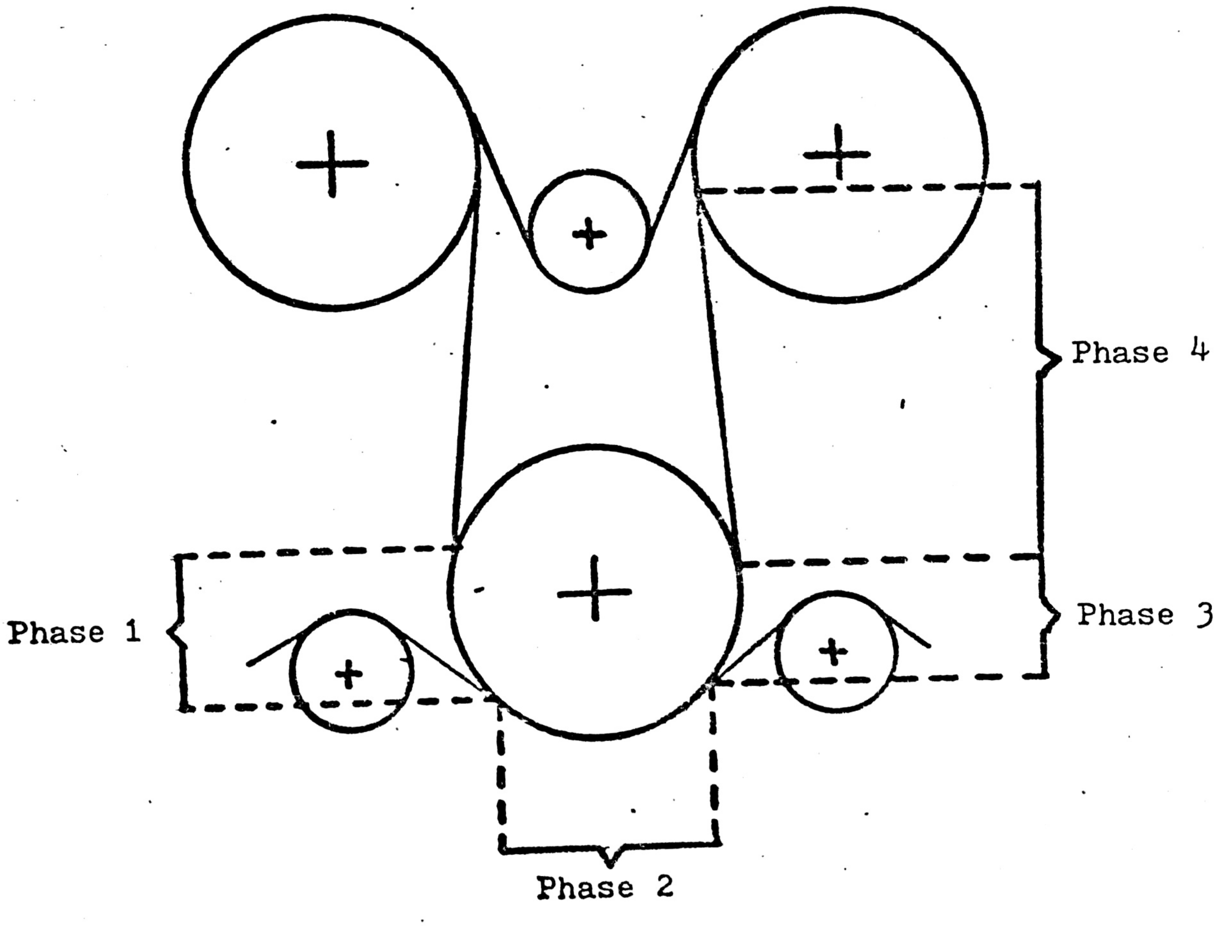
The falling rate zone continues from this point up to the reel. Studies by Sherwood (2) indicated a continuous drop in the rate of evaporization throughout the falling rate zone. At the end of the falling rate period it is extremely important to keep the temperature of the felt well above that of the sheet, or the removal of the last percentages of water will not be possible due to recondensation of water on the surface of the sheet cooled by the felt (1).

Four Phases of Drying

The drying process can be broken down further into a

four phase system around each of the dryer cans. The first phase begins as the sheet comes into contact with the dryer cylinder and continues until the felt contacts the sheet. Phase two is the period in which the felt is in contact with the sheet holding it against the dryer. Phase three is the time the sheet remains in contact with the dryer with no felt contact, and phase four begins with the release of the sheet from the dryer. The cycle begins again as the sheet contacts the next dryer cylinder (see Fig. 1).

FIG. 1 Four Phases of Drying



The first zone is a very short one in which there is little evaporization or fluid transfer taking place (4). It is basically a warming up zone where the temperature of the sheet is slowly raised after cooling in the dryer pocket.

In the second phase of drying the sheet experiences a much more rapid heating than in the previous phase. This is caused by the pressure of the felt forcing the sheet into a more intimate contact with the dryer cylinder. The increased contact gives a better coefficient of heat transfer and the rate at which the temperature increases continues to rise until an equilibrium is reached. At this point there is a balance between the amount of vaporization at the dryer surface and the amount of vapor being transferred to the air through the felt. It is estimated that up to 80% of the water removed leaves in this phase when the felt is in contact with the sheet (2).

As the sheet looses contact with the felt, the third phase begins. With the splitting of the felt from the sheet, both of the previously contacting surfaces are exposed to the dryer pocket conditions and vaporization occurs (4). The temperature of the sheet is lowered by this evaporization and the amount of steam released from the sheet decreases. The temperature of the sheet also decreases due to the loss of intimate contact between the sheet and the dryer surface when the dryer felt is removed.

In the fourth phase the paper web separates from the dryer cylinder and the vapor which was previously trapped

between the sheet and the drying cylinder is able to flash off. There is also still some evaporization occurring from the previously exposed surfaces though they have cooled extensively. Accompanying the flashing of vapor and the evaporization is a rapid cooling of the sheet before it finally contact the next dryer surface starting the cycle again.

Water Movement Within the Sheet

During phases one, two, and three there are two interrelated movements occurring within the structure of the paper web (5). One is the movement of latent heat and the other is the transfer of water and steam. As the sheet comes into contact with the dryer surface, the layer of water it contacts is raised to its vaporization temperature. The vapor that is formed passes up through the web until it condenses, releasing its heat into the sheet. As this action continues, the level at which recondensation takes place is gradually moved upward toward the felted surface. Eventually the steam is able to pass all the way through the sheet, and if the felt is sufficiently hot, the steam is carried away in the dryer pocket. If the felt is too cool, the steam will recondense in the felt or at the paper surface.

Preston (6), working with textiles and dyestuffs, showed that at the same time that this was occurring, there is also a movement of the recondensed vapor back to the dryer

surface through capillary action. Dreshfield and Han studied the drying of laminated sheets soaked with a non-volatile dye, and by measuring the moisture within the layers, showed that the liquid migrates in order to fill the interstices which were vacated (7). This migrating action maintains a saturated surface at the dryer-paper interface. As the amount of moisture in the sheet decreases, the sheet is unable to keep the surface saturated and the amount of vaporization decreases. The decrease in surface evaporation is compensated for by an increase in the level of internal evaporation which occurs as the sheet is heated. The internal evaporization and vapor diffusion becomes more prevalent as void spaces begin to form within the sheet making the structure more porous. This is the mechanism of the constant rate zone. When the internal vaporization can no longer make up for the loss of evaporization at the unsaturated surface, the drying rate begins to decrease. As the sheet becomes very nearly dry, the remaining moisture becomes trapped in a pendular state as is tries to flow from the interior of the sheet to either of the surfaces (8). When there is no longer any water at the dryer surface, the coefficient of heat transfer drops and there is a decrease in the sheet temperature. The temperature of the last dryers must be maintained sufficiently high for enough heat to be transferred through the fiber structure up to the level of the trapped moisture. This forces the gradual movement of the liquid layer out of the sheet as the heat penetration into the fiber structure increases. Finally all of the removable moisture is forced out through the felt leaving the sheet dry.

## PURPOSE OF THE DRYER FELT

The dryer felt serves a variety of purposes on the paper machine. It acts as a conveyor to carry the wet sheet through the dry end and it imparts a finish to the surface of the sheet, but its main purpose is to hold the sheet against the dryer cylinders and to help in the removal of water. Since 80% of the water removal occurs when the sheet is in contact with the felt, it is fairly obvious that the felt must be able to do one of several things. It must either absorb water, allow the water vapor to pass through it, or carry the water to a place where it can be evaporated. Actually, it performs all of the mentioned functions and how well it can do them determines the effectiveness of the felt.

## EFFECT OF INCREASED FELT TENSION ON THE DRYING RATE

Any felt can be made to do additional drying by simply increasing its tension. This phenomenon is due to the increased coefficient of heat transfer which accompanies the tension increase (9,10). Tests by Young showed that fifty percent more water is condensed in a dryer when the sheet tension is increased. Studies by Attwood and Smith (9) on their experimental machine demonstrated that up to 43% increase in the drying rate could be obtained from the increased felt tension.

The increase in heat transfer is attributable to the dispersion of the layer of air which is trapped in the nip formed by the dryer cylinder, the sheet, and the felt. This layer of air can account for as much as 83% of the heat transfer resistance in the dryer section (11). The tension of the felt holding the sheet against the dryer produces a pressure equal to the tension per unit width divided by the radius of curvature of the dryer. If the pressure of the vapor layer trapped between the sheet and the dryer reaches and passes this pressure as it expands, the sheet is lifted off the dryer surface reducing the heat transfer. The pressure which is required to disperse the insulating layer of air through the sheet, and thus eliminate its effect, is labeled the threshold pressure. For moisture contents between 20% and 80% it is equal to a pressure difference across the sheet of about 0.2 pli (12). Once the threshold

pressure has been reached, the heat transfer coefficient is at a maximum and further tension increases have been found by Brundrett and Baines (13) on their experimental machine to give no added increase to the drying rate. This is important when it is considered that excess felt tension can cause problems such as felt roll and journal damage, uneven felt stretching, seam failure, and increased friction throughout the dry end requiring more energy.

The other way that the felt tension helps to increase the drying capacity of a machine is in liquid migration to the paper surface. This helps to keep a saturated surface on the dryer cylinder and thus maximizes heat transfer.

The problems now seem to be to determine the best location for the increased tension, the degree of tension increase, and the effect of increased tension on the finished properties of the sheet.

# EXPERIMENTAL PROCEDURE

The purpose of the following experiment was to determine the effect that the amount of tension applied to a dryer fabric has on the moisture removal in the dryer sections of a paper machine.

The basic design of the experiment was to show the effect of increases in the fabric tension on the moisture in the wet section, the dry section, and then both sections at the same time.

## Tension Calculations

Before running the trial, it was necessary to establish the range of tensions to be used and the weights which would have to be applied to achieve these fabric tensions.

The amount of tension needed to disperse the insulating layer of air trapped beneath the sheet was calculated using the equation for the dispersion of a thin layer of air through a permeable membrane: 0.2 = Optimum Fabric Tension ÷ Dryer Can Radius. Since the radius of the dryer cylinders to be used measured 14 inches, the optimum tension was calculated as 2.8 pli. In order to show the effect of increasing the tension of the fabric from near zero to above the optimum tension the following tensions were picked to use: 0.5, 1.0, 2.0, 3.0, and 4.0 pli.

The tension applied to the fabric was adjusted using

a weight loaded tension roll, so to achieve the desired tensions, the appropriate weights had to be calculated. This was done using the equation: Tension = Applied Force ÷ (2 X Fabric Width). But since the tension mechanism consisted of a 12 inch lever arm connected to the pivoting tension roll, the applied force equaled the applied weight divided by 12. This gave the final equation for the necessary weights of : Desired Fabric Tension X (2 X Fabric Width) ÷ 12 with the fabric width being equal to 26.5 inches. The desired tensions were achieved using a set of weights in different combinations.

Machine Trial Conditions

The paper machine used to run the trials was the pilot plant machine at Western Michigan University. It was clothed with a 100% monofilament fabric which had an air permeability of 450 cfm.

In previous experiments done by Attwood and Smith (9), Nuttall (13), and Brundrett and Baines (11) the furnish used was different and was not thought to be of great importance. So for simplicities sake, a standard furnish and sheet weight were used, The pulp was a blend of 70% hardwood and 30% softwood with a freeness of 450csf. The machine speed was set at 75 fpm, and to insure that drying would occur down the full length of the machine, the machine was made to be dryer limited with a reel moisture of 10%. Once all of these conditions were met, the sheet weight was set at

40# per 3300 $ft^2$. The machine was then allowed to run for fifteen minutes until all of the conditions stabilized.

Sampling Procedures

After the machine had stabilized, three sets of tests were run. In Run A the dryer fabric tension in the first section was varied from 0.5 pli through the full tension range. During this set, the tension in section two was kept constant at the optimum tension. This run was to show the effect of increasing the fabric tension on the moisture removal at the wet end of the machine. Run B was to show the effect of tension at the dry end of the machine. In Run B, the second section dryer fabric was varied through the entire tension range while the first section tension was left constant at the optimum. The third run, Run C, was done to show the maximum change possible in the amount of moisture removed in both sections. For this set, the tensions in both the first and second sections were set at the lowest level and a run was made. The tensions in both were then adjusted to the maximum and another run was made.

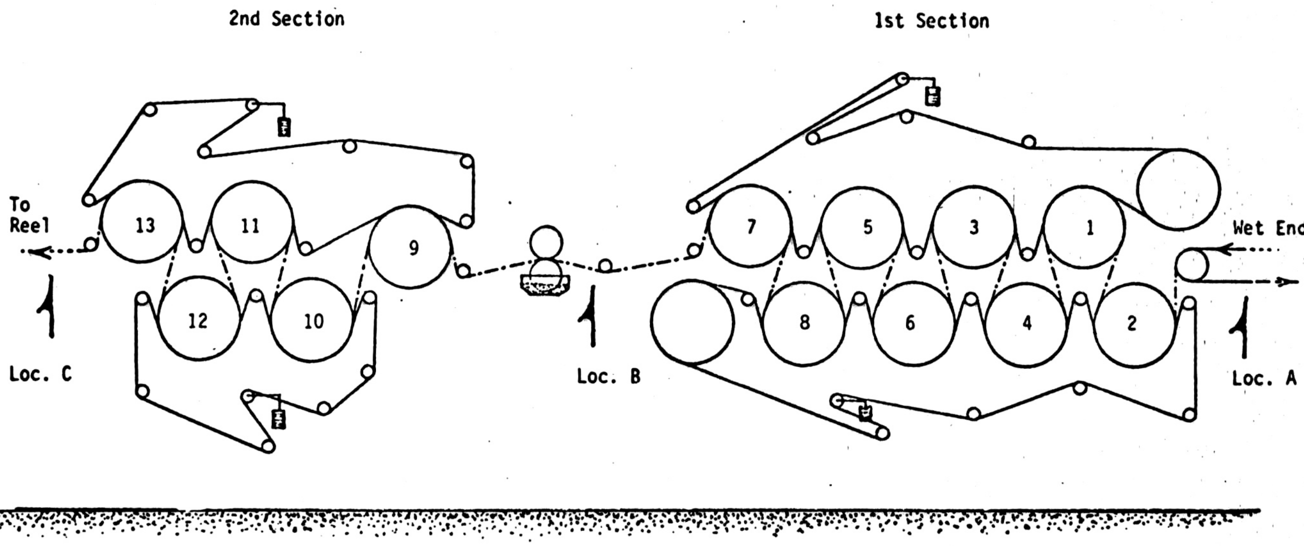
In each of the previously described sets of tests, the following sampling procedures were used. Before starting a run, the temperatures of dryers numbers 3, 6, 11, and 12 were measured to check for significant variations. The appropriate weights were then applied to the fabric tension devices and the machine was allowed to run for five minutes to stabilize at the new conditions. Paper samples were

taken at the three locations down the machine designated on Figure 2. At each location, three areas of the sheet were tested. Sample Set 1 was taken from the back side of the sheet, Set 2 from the center, and sample Set 3 from the front side. The samples were taken in the following manner. As the sheet passed through the draw between the wet press and the first section (Loc. A), three 2 inch dia. samples were taken using the "bear trap" sampler as quickly as possible, one directly behind the other. The sheet was then allowed to pass through the first section into the draw between the two dryer sections. At Location B, three more samples were taken as close as possible to the previously sampled areas. After the sheet had passed through the second section to location C, the final three samples were taken, again, as near to the previously sampled area as possible. As the sheet reached the reel, a sample was torn off which contained the entire sample area. All of the samples were immediately placed into plastic bags which were sealed for storage. The same procedure was used for the other two location on the sheet. After all of the samples had been taken, the dryer can temperatures were rechecked and the weights changed for the next tension condition. The machine speed was monitored throughout the trial and was kept constant.

Testing Procedures

The bagged samples were kept in cold storage until

they could be tested. The samples were removed from their bags one at a time and weighed on a Mettler Balance. They were then placed in tared containers and dried in an oven at 200°F for approximately one hour. The dried samples were again weighed and then disposed of. The wet and dry weights were used to calculate the percent moistures of the samples. From the sample of the sheet removed at the reel, a 1 inch by 12 inch sample was removed and dried in the oven. It was then reweighed and the grams of O.D. fiber / $ft^2$ recorded.




Sampling Locations

Figure 2

## PRESENTATION OF RESULTS

The percent moisture values and the grams O.D. fiber per $ft^2$ were used for each sample to calculate the grams of water per $ft^2$. This number along with the percent moistures for Runs A, B, and C are listed in Tables 2, 3, and 4. By using the grams of water per $ft^2$, the effect of changes in the basis weight of the sheet was eliminated, but there were still differences in the percent moisture of the sheet coming in to the first section. Because of this, it was not possible to directly relate the grams of water per $ft^2$ removed by each section. Instead the percent of the moisture coming into the section which was removed was calculated and used as a relative comparison for moisture removal. The percent of the incoming moisture removed will be the numbers compared for the rest of the report and shall be referred as the percent moisture from here on. The percent moisture removed figures are listed in Tables 2, 3, and 4 for Runs A, B, and C, respectively.

There are several sets of numbers which were obviously incorrect due to some error in testing for Run B. These numbers were disregarded.

## % Moisture Of Samples

| Sheet location | 1 | | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Machine location | A | B | C | A | B | C | A | B | C |
| 0.5 pli | 57.9 | 18.2 | 12.7 | 56.8 | 19.0 | 13.0 | 57.1 | 24.3 | 13.3 |
| 1.0 pli | 57.9 | 22.7 | 12.8 | 57.8 | 20.3 | 13.5 | 57.3 | 19.6 | 11.4 |
| 2.0 pli | 57.0 | 18.8 | 12.2 | 56.7 | 17.8 | 9.9 | 56.7 | 17.1 | 10.4 |
| 3.0 pli | 56.0 | 15.8 | 7.6 | 56.6 | 10.3 | 7.0 | 55.7 | 9.3 | 6.7 |
| 4.0 pli | 56.2 | 17.3 | 10.8 | 55.9 | 15.4 | 9.7 | 55.9 | 16.4 | 9.7 |

## Grams Water / $Ft^2$

| Sheet location | 1 | | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Machine location | A | B | C | A | B | C | A | B | C |
| 0.5 pli | 7.45 | 1.21 | 0.79 | 7.25 | 1.29 | 0.82 | 6.88 | 1.66 | 0.80 |
| 1.0 pli | 7.51 | 1.60 | 0.80 | 7.26 | 1.35 | 0.83 | 6.85 | 1.24 | 0.66 |
| 2.0 pli | 7.10 | 1.24 | 0.74 | 6.82 | 1.13 | 0.57 | 6.72 | 1.06 | 0.60 |
| 3.0 pli | 6.59 | 0.97 | 0.43 | 6.64 | 0.58 | 0.38 | 6.26 | 0.51 | 0.36 |
| 4.0 pli | 6.86 | 1.21 | 0.65 | 6.69 | 0.96 | 0.57 | 6.70 | 1.04 | 0.57 |

## % of Incoming Moisture Removed

| Sheet Location | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Machine location | A to B | B to C | A to B | B to C | A to B | B to C |
| 0.5 pli | 83.8 | 34.7 | 82.2 | 36.4 | 75.9 | 51.8 |
| 1.0 pli | 78.7 | 50.0 | 81.4 | 38.5 | 81.9 | 46.8 |
| 2.0 pli | 82.5 | 40.3 | 83.4 | 49.2 | 84.2 | 43.4 |
| 3.0 pli | 85.3 | 55.7 | 91.2 | 34.5 | 91.8 | 29.4 |
| 4.0 pli | 82.3 | 46.3 | 85.6 | 40.6 | 84.5 | 45.2 |

TABLE 2

**Data For Run A**

% Moisture Of Samples

| Sheet location | 1 | | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Machine location | A | B | C | A | B | C | A | B | C |
| 0.5 pli | 6.9 | 16.7 | 19.1 | 54.7 | 18.0 | 12.2 | 54.6 | 12.0 | 11.7 |
| 1.0 pli | 51.1 | 3.6 | 9.8 | 52.2 | 12.2 | 11.2 | 55.3 | 12.7 | 9.6 |
| 2.0 pli | 53.3 | 17.4 | 12.8 | 55.3 | 16.0 | 12.4 | 55.5 | 19.2 | 12.4 |
| 3.0 pli | 53.2 | 15.5 | 12.2 | 52.4 | 14.2 | 11.5 | 50.9 | 13.5 | 11.6 |
| 4.0 pli | 44.6 | 10.9 | 8.7 | 43.3 | 7.4 | 6.4 | 44.2 | 6.9 | 6.8 |

Grams Water / $Ft^2$

| Sheet location | 1 | | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Machine location | A | B | C | A | B | C | A | B | C |
| 0.5 pli | 0.39 | 1.01 | 1.19 | 6.09 | 1.11 | 0.71 | 6.09 | 0.69 | 0.67 |
| 1.0 pli | 5.46 | 0.20 | 0.57 | 5.68 | 0.72 | 0.66 | 6.38 | 0.75 | 0.55 |
| 2.0 pli | 6.51 | 1.20 | 0.84 | 6.72 | 1.04 | 0.77 | 7.11 | 1.35 | 0.81 |
| 3.0 pli | 6.46 | 1.04 | 0.79 | 6.42 | 0.96 | 0.76 | 5.83 | 0.88 | 0.74 |
| 4.0 pli | 4.43 | 1.34 | 0.52 | 4.41 | 0.46 | 0.40 | 4.36 | 0.41 | 0.40 |

% of Incoming Moisture Removed

| Sheet location | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Machine location | A to B | B to C | A to B | B to C | A to B | B to C |
| 0.5 pli | - | - | 81.8 | 36.9 | 88.7 | 2.9 |
| 1.0 pli | - | - | 87.3 | 8.3 | 88.2 | 26.7 |
| 2.0 pli | 81.6 | 30.0 | 84.5 | 26.0 | 81.0 | 40.0 |
| 3.0 pli | 83.9 | 24.0 | 85.0 | 20.8 | 84.9 | 15.9 |
| 4.0 pli | 69.8 | 61.2 | 89.6 | 13.0 | 90.6 | 2.4 |

TABLE 3

Data for Run B

### % Moisture of Samples

| Sheet location | 1 | | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Machine location | A | B | C | A | B | C | A | B | C |
| 0.5 pli | 55.3 | 17.4 | 10.9 | 55.8 | 17.9 | 11.2 | 55.8 | 18.3 | 11.7 |
| 1.0 pli | | | | | | | | | |
| 2.0 pli | | | | | | | | | |
| 3.0 pli | | | | | | | | | |
| 4.0 pli | 56.3 | 20.8 | 14.2 | 56.8 | 17.9 | 11.4 | 54.3 | 15.1 | 10.7 |

### Grams Water / $Ft^2$

| Sheet location | 1 | | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| Machine location | A | B | C | A | B | C | A | B | C |
| 0.5 pli | 6.99 | 1.19 | 0.06 | 7.45 | 1.29 | 0.74 | 7.35 | 1.30 | 0.77 |
| 1.0 pli | | | | | | | | | |
| 2.0 pli | | | | | | | | | |
| 3.0 pli | | | | | | | | | |
| 4.0 pli | 7.42 | 1.51 | 0.95 | 7.02 | 1.16 | 0.69 | 6.61 | 0.99 | 0.67 |

### % of Incoming Moisture Removed

| Sheet location | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Machine location | A to B | B to C | A to B | B to C | A to B | B to C |
| 0.5 pli | 83.0 | 95.0 | 82.7 | 42.6 | 82.3 | 40.8 |
| 1.0 pli | | | | | | |
| 2.0 pli | | | | | | |
| 3.0 pli | | | | | | |
| 4.0 pli | 79.6 | 37.1 | 83.5 | 40.5 | 85.0 | 32.3 |

TABLE 4

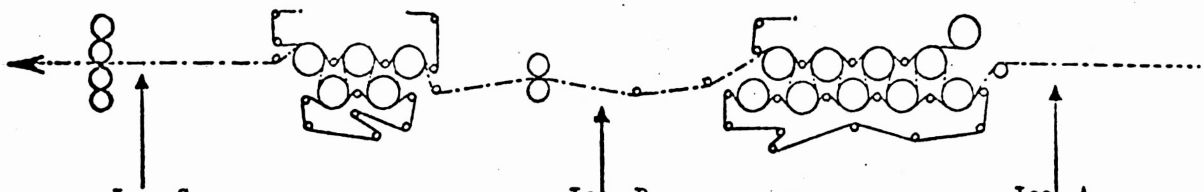
Data for Run C

## DISCUSSION OF RESULTS

When looking at the results for Run A presented in Figure 3, a definite pattern can be seen for the first section. As the tension is increased from 0.5 to 1.0 pli, there is little change noted for Locations 1 and 2 with an increase in the percent moisture removed for Location 3. Further increases in tension from 1.0 to 2.0, and finally to the optimum level of 3.0, caused increases in the moisture removal for all three locations. As the tension was increased to 4.0 pli, the amount of moisture removed dropped off in all three cases. This pattern follows what would be expected according to the previous testing which has been reported in the literature (9). The data indicates that as the fabric tension is increased at the wet end of the paper machine, the amount of the incoming moisture which is removed increases until the optimum tension is achieved. It is at this point that the results fail to follow the expected pattern. According to the previous testing, a plateau should have been reached once the optimum tension was applied to the fabric. But this is not the case. As is clearly indicated by the results, when the tension exceeds the optimum, some unpredicted mechanism takes over and the efficiency with which the dryers remove water decreases. There seems to be no reasonable explanation for this affect, but it is possible that internal entrapment of moisture by the extremely tight fabric is occurring.

Figure 3 - Run A

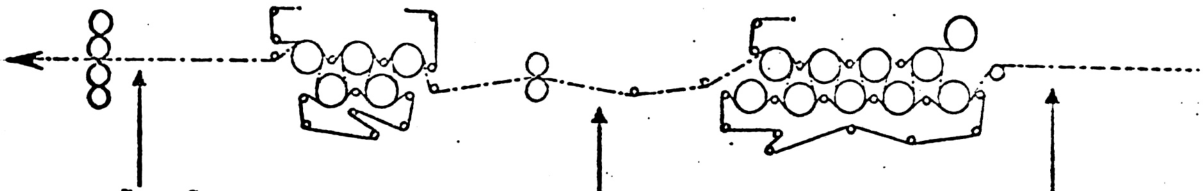
% water removed



| pli | Loc. C (g water/ft$^2$) | % removed | Loc. B (g water/ft$^2$) | % removed | Loc. A (g water/ft$^2$) | Sheet Loc. |
|---|---|---|---|---|---|---|
| 0.5 | 0.79 | 34.7% | 1.21 | 83.8% | 7.45 | |
| 1.0 | 0.80 | 50.0% | 1.60 | 78.7% | 7.51 | |
| 2.0 | 0.74 | 40.3% | 1.24 | 82.5% | 7.10 | 1 |
| 3.0 | 0.43 | 55.7% | 0.97 | 85.3% | 6.59 | |
| 4.0 | 0.65 | 46.3% | 1.21 | 82.3% | 6.86 | |
| 0.5 | 0.82 | 36.4% | 1.29 | 82.2% | 7.25 | |
| 1.0 | 0.83 | 38.5% | 1.35 | 81.4% | 7.26 | |
| 2.0 | 0.57 | 49.6% | 1.13 | 83.4% | 6.82 | 2 |
| 3.0 | 0.38 | 34.5% | 0.58 | 91.2% | 6.64 | |
| 4.0 | 0.57 | 40.6% | 0.96 | 85.6% | 6.89 | |
| 0.5 | 0.80 | 51.8% | 1.66 | 75.9% | 6.88 | |
| 1.0 | 0.66 | 46.8% | 1.24 | 81.9% | 6.85 | |
| 2.0 | 0.60 | 43.4% | 1.06 | 84.2% | 6.72 | 3 |
| 3.0 | 0.36 | 29.4% | 0.51 | 91.8% | 6.26 | |
| 4.0 | 0.57 | 45.2% | 1.04 | 84.5% | 6.70 | |

Figure 4 - Run B

% water removed



| pli | Loc. C (g water/ft.$^2$) | % Removed | Loc. B (g water/ft.$^2$) | % removed | Loc. A (g water/ft.$^2$) | Sheet Loc. |
|---|---|---|---|---|---|---|
| 0.5 | 1.19 | - | 1.01 | - | 0.39 | |
| 1.0 | 0.57 | - | 0.20 | - | 5.46 | |
| 2.0 | 0.84 | 30.5% | 1.20 | 81.6% | 6.51 | 1 |
| 3.0 | 0.79 | 24.0% | 1.04 | 83.9% | 6.46 | |
| 4.0 | 0.52 | 61.2% | 1.34 | 61.2% | 4.43 | |
| 0.5 | 0.71 | 36.9% | 1.11 | 81.8% | 6.09 | |
| 1.0 | 0.66 | 8.3% | 0.72 | 87.3% | 5.68 | |
| 2.0 | 0.77 | 26.0% | 1.04 | 84.5% | 6.72 | 2 |
| 3.0 | 0.76 | 20.8% | 0.96 | 85.0% | 6.42 | |
| 4.0 | 0.40 | 13.0% | 0.46 | 89.6% | 4.41 | |
| 0.5 | 0.67 | 29.0% | 0.69 | 88.7% | 6.09 | |
| 1.0 | 0.55 | 26.7% | 0.75 | 88.2% | 6.38 | |
| 2.0 | 0.81 | 40.0% | 1.35 | 81.0% | 7.11 | 3 |
| 3.0 | 0.74 | 15.9% | 0.88 | 84.9% | 5.83 | |
| 4.0 | 0.40 | 2.4% | 0.41 | 90.6% | 4.86 | |

When the results for the second section of Run A are considered, there is no noticeable pattern as the fabric tension is increased. This is probably due to the fact that the sheet is nearly dry and has a very porous structure in the second section. A high tension is therefore unnecessary for the dispersion of the insulating layer of air. This theory is supported by the results for Run B shown in Figure 4. There is again no noticeable pattern found in the percent removed figures for the second section. This would indicate that increases in fabric tension at the dry end of the machine may have only a minimal effect.

Run C did not show what was intended. Originally, it was hoped that the maximum possible gain in percent moisture removed would be illustrated in the run. But the unexpected drop in percent moisture removed at the tension above optimum caused this run to fail. However, to get a grasp of the magnitude of the possible increase, the percent moisture removed in Run A at 0.5 and 3.0 pli could possibly be used. In these sets, the tension in the first section was varied in the same manner as in Run C, but section two was left constant at the optimum. As previously discussed, the second section fabric tension seems to have little to do with the total percent moisture removed in both sections. To verify this, the percent incoming moisture removed from the wet press to the reel was calculated for the conditions when the second section tension was varied from 0.5 pli to the optimum. As can be seen in Table 5, there was no overall effect from the tension change. Knowing this, the figures

for Run A should be accurate for use in determining the total possible gain from increase fabric tensions. When the percent moisture removed at 0.5 pli and then at 3.0 pli are compared for all three sheet locations, see Table 6. The maximum possible increase which can be realized from tension increased is seen to be six percent.

| Sheet location | 1 | 2 | 3 |
|---|---|---|---|
| 0.5 pli | - | 88 | 89 |
| 1.0 pli | 90 | 88 | 91 |
| 2.0 pli | 87 | 89 | 89 |
| 3.0 pli | 88 | 88 | 87 |
| 4.0 pli | 88 | 91 | 91 |

TABLE 5 Run B

Total % water removed
($g$ water / $ft^2$)

| Sheet location | 1 | 2 | 3 |
|---|---|---|---|
| 0.5 pli | 89 | 89 | 88 |
| 1.0 pli | 89 | 89 | 90 |
| 2.0 pli | 90 | 92 | 91 |
| 3.0 pli | 94 | 94 | 94 |
| 4.0 pli | 91 | 92 | 92 |

TABLE 6 Run A

Total % water removed
($g$ water / $ft^2$)

## CONCLUSION

From this experiment, several conclusions can be drawn. First, the positive effect which increasing the tension of the dryer fabric has on the moisture removal has been verified. It has been shown to be most beneficial in the wet sections of a paper machine with very little benefit being realized after the sheet becomes fairly dry. For this particular machine, the percent of the incoming moisture which was removed from the sheet was increased by six percent as the fabric tension was increased from nearly zero up to the optimum tension.

Secondly, contrary to the previously established theory, the positive results achieved by increasing the fabric tension do not appear to level off and remain constant once the optimum level has been exceeded. It instead shows a substantial negative effect, causing lower percent of moisture to be removed. This becomes important when one considers the fact that many papermakers exceed the optimum tension to insure that they are getting maximum efficiency, when according to this study, they are in fact doing the opposite.

To get the maximum benefit from the dryer fabric, the optimum tension should be calculated and used in the first section. The tensions should probably be run lower as the sheet dries since the possible minor positive effect would most likely be negated by increases in machine and fabric

wear. The fabric tension should not be run above optimum tension as this would be detrimental to the drying efficiency.

## SUGGESTIONS FOR FURTHER WORK

Although this study has illustrated that increasing the dryer fabric tension can cause a substantial increase in the amount of drying that can be achieved by a dryer section, it leaves several areas open for further study.

Another study similar to this one, but with several machine trials to give a more substantial data base, could be run. This would help to give final verification of the results obtained in this experiment. If the study is repeated, it is suggested that not only the percent moisture coming into the section which is removed be studied, but also the amount of steam condensate for each section. This would give two different sets of data for each sample which could be compared to check for similar trends.

Another possible area of study would be an attempt to verify and explain the apparently detrimental effect that increasing the tension above the optimum seems to have. This is a result which was not predicted in any of the previous literature or testing and would be of interest to paper-makers.

The final suggestion is to study the effect of increased fabric tension on the final physical and optical properties of the sheet.

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