# FLUID IMBIBITION BEHAVIOR OF NONWOVENS CONTAINING CELLULOSE ACETATE AND ITS BLENDS WITH SYNTHETIC AND OTHER CELLULOSIC FIBERS

**Bhupender S. Gupta**
**College of Textiles**
**North Carolina State University**
**Raleigh, NC**
**Edward J. Powers**
**Celanese Acetate LLC**
**Charlotte, NC**

## Introduction

Among the fibers used widely for absorbent applications are cotton, pulp, and rayon, all largely cellulosic. One common attribute these materials provide is hydrophilicity which is needed in order to attract, imbibe, and hold fluid in the structure. Research of the past decade has shown that a second characteristic that plays a critical role in determining the amount of fluid absorbed and the rate at which it is imbibed is the resiliency of the web. This is governed by both the chemical and physical properties of the fiber and the structure of the web. For a given fabric structure, differences in resiliency of the fibers lead to differences in the absorbency performance. Work of the past few years has illustrated that webs containing cotton usually show superior absorbency values than do comparable webs containing rayon. This has been primarily ascribed to the fact that the wet resiliency of cotton is several times greater than that of rayon. When a hydrophilic fiber comes in contact with an aqueous fluid, the latter diffuses into the structure. It disrupts intermolecular bonds, reduces modulus, and causes a collapse of the fabric in terms of the thickness. This results in a reduction (1) in the interstitial space and, therefore, in absorbent capacity, and (2) in the pore size, and, therefore, in absorbency rate. In order to improve resiliency of a structure containing a hydrophilic fiber, studies have considered using blends, with the second material a synthetic fiber, either a polyolefin or a polyester [3,4], which absorb little or no fluid in the internal structure. This procedure has proved useful, particularly when the cellulosic fiber is rayon [6].

An alternative to using blends of a hydrophilic and a hydrophobic material, would be to use a fiber that combines the features of both, i.e. it has hydrophilic groups that attract fluid but at the same time the amount it absorbs into the internal structure is small and, therefore, the resiliency it loses upon wetting is also small. Keeping this concept in mind, a project was undertaken about two years ago in which the primary fiber material considered was cellulose acetate. The fiber being only partially acetylated (d.s. 2.3), it has hydroxyl groups in the chains which impart a hydrophilic character to the material. However, these molecules amount to only about 23% of the total pendant groups - as compared to 100% in natural or regenerated cellulose - and, therefore, the rest of the structure is hydrophobic and contributes to wet resiliency. This last feature also makes the material largely thermoplastic, which means that a structure containing it can be bonded by heat, in addition to by other methods, such as needling and hydroentangling, used on celluloses. This adds versatility to the material and makes it a potentially attractive candidate for applications in absorbent products. A review of literature had indicated that no significant study existed which examined the absorbency behavior of webs containing cellulose acetate. The present study was, therefore, undertaken to close a part of this gap. The objectives were to examine the effects produced by some of the important processing and structural factors and generate an understanding of the absorbency characteristics of webs containing the fiber.

The investigation included two main experiments. In one, webs containing blends of a cellulose acetate and a hydrophilic cellulose fiber, and a cellulose acetate and a hydrophobic synthetic fiber, were prepared and mechanically bonded using needling and hydroentangling. Web composition, areal density, and bonding level and type were the variables whose effects were examined. In the second, webs containing blends of a cellulose acetate fiber and a low melt polyester fiber were prepared and thermally bonded using a through-air system. In this, the fraction of low melt fiber in the structure and the bonding particulars were the factors of the study.

## Experimental

### Materials

The cellulose acetate fiber is available in a regular round and a trilobal cross-sectional shapes and in a number of sizes. The fibers of trilobal shape and two different deniers, 3.3 and 1.7, were chosen as the material for the research. For comparison, and for varying web composition over a broad range by blending cellulose acetate with another material, a hydrophilic cellulosic fiber and a hydrophobic synthetic fiber were also selected. The hydrophilic material chosen was the trilobal rayon (Galaxy) of 3 denier and the hydrophobic fiber selected was polypropylene, also of 3 denier. For developing thermally bonded structures and studying their absorbency, cellulose acetate was mixed with a low melt fiber and bonded by the through - air heating system. For this purpose, a low melt polyester of 4 denier was selected.

### Processing

The fibers were opened, blended in the desired ratios, and carded and cross-lapped to produce webs of three different areal densities, which were 40, 80, and 120 g/m$^2$. The webs

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contained blends of cellulose acetate (CA) with Galaxy Rayon (GR), and of cellulose acetate with polypropylene (PP), in the ratios 100/0, 67/33, 33/67 and 0/100. In the main experiment, the fabrics were bonded by needling and hydroentangling. For the former, the process was carried out on a Dilo machine with needles from Groz Backert, and a depth of needle penetration through the fabric of 7 mm. The structures were entangled to three different intensities, i.e. 0, 40 and 80 needles/$cm^2$. These were designated as N0, N1, and N2, respectively. The webs were needled from one side only.

For hydroentangling, a Honeycomb unit was utilized. Three variations were used: control (H0), low entangling (H1), and high entangling (H2). In the first, the web was only soaked (statically) in water, extracted and dried. In the second, a web was hydroentangled with the manifolds operating at 400, 600, and 800 PSI, respectively, for the front, middle, and the back spray rolls. In the third variation, the manifold pressures used were 600, 800, and 1000 PSI, respectively, for the front, middle and the back spray rolls. As done with the needled structures, the webs were hydroentangled from only one side. The belt speed and the conveyor mesh count were maintained constant at 20 ft/minute and 100/90 epi/ppi, respectively. After entangling, a web was passed through the Evac water extraction unit at 25 ft/minute under a vacuum of 5 mm Hg. It was then vacuum dried by passing through the Fleissner dryer. The conditions used were cylinder linear speed 16'/ min, fan speed 300 rpm, and air temperature $290^0$F.

In the experiment involving through-air thermal bonding, two structures of approximately 80 g/$m^2$, one a 85/15 and the other a 70/30 cellulose acetate/low melt polyester blend, were prepared on a carding/cross-lapping unit. These were bonded by passing the webs through the Fleissner dryer at 346 $^0$F air temperature. The residence time was varied by changing the drum linear speed. Three speeds were used which were 10, 15, and 20 ft/minute.

**Characterization**

Characterization of absorbency was carried out on the Gravimetric Absorbency Testing System (GATS) (Figure 1), equipped with a specimen cell which allowed measurements of web thickness at two positions diagonally across from each other while holding the specimen in place for absorbency. The fluid (1% saline) was delivered from a single hole in the middle and spread radially outward through the specimen (Figure 2). The specimen was of a circular shape obtained by cutting the fabric with a die of 6.03 cm diameter. The tests were conducted under a hydrostatic pressure head of zero ($\Delta$P=0, Figure 1) and an environmental pressure of 12 gf/$cm^2$, obtained by placing fixed weights on the web. An example of the output, given in terms of the voltage but later converted into the units of gram or millimeter, as appropriate, is given in Figure 3, which illustrates three lines, two representing the thickness values and one the amount of fluid absorbed.

Two parameters were assessed: the absorbent capacity, C (g fluid / g dry mass), and absorbency rate, Q (g fluid / g dry mass - sec). The former was obtained by dividing the volume of fluid absorbed at equilibrium with the dry mass of the web. The latter was measured in the time interval corresponding to 20% and 80% of the maximum amount of fluid absorbed by taking the slope of the fluid uptake line and dividing it by the dry mass of the web (Figure 4).

**Prediction of Behavior Using Theoretical Models**

For understanding the results obtained, it is useful to consider models that can be used to characterize the absorbency behavior. Two such models, one for the capacity and the other for the rate, the latter based on a modification of Washburn-Lucas theory [8, 9], have been presented earlier [2, 5]. The models are as follows:

$$C' = A\,\rho_l\,[\,T/W_f - 1/A\rho_f\,]$$
$$Q' = [\rho_l\,\pi\,r\,\gamma\,\cos\theta\,]\,[\,T/W_f - 1/A\rho_f\,]\,/\,2\,\eta$$

In these, A and T are, respectively, the area and the final thickness of the test specimen (Figure 2), $\rho_l$ and $\rho_f$ are, respectively, the densities of the fluid and the fiber, $\gamma$ and $\eta$ are, respectively, the surface tension and the viscosity of the fluid, $\theta$ is the advancing contact angle of the fluid - fiber system, and r is the mean radius of the pores in the structure. The values of all parameters in the above models, except $T/W_f$ and r, are either known or measured using standard procedures. The value of $T/W_f$ was computed from the measurements of the dry mass $W_f$ of a web prior to each test and of the thickness T on GATS during the tests. The value of r was predicted with a model discussed elsewhere [3].

According to the above equations, capacity is primarily determined by the thickness of the web in the wet state per unit dry mass ($T/W_f$). The rate is also affected by this factor directly but, additionally, by the pore size (r), the cosine of the contract angle $\theta$, and the surface tension of the fluid ($\gamma$), directly, and the viscosity of the fluid ($\eta$), indirectly. The factors that affect $T/W_f$ are the size, shape, and the wet mechanical properties of the fiber, and the type and the extent of bonding in the web. Needling, for example, creates channels in the direction of flow which impart resiliency to the web and resist collapse when subjected to pressure. This tends to lead to a higher value of $T/W_f$. The factors that affect pore size are those that affect $T/W_f$, plus fiber size. Contact angle is an interaction parameter whose value is affected by the nature of the fiber surface and the properties of the fluid. With water as the fluid, a hydrophilic surface, such as that of cellulose, gives low $\theta$ and, therefore, leads to high rate. However, it should be noted that if a fluid, such as

water, reacts with a fiber, it can lead to a loss in resiliency, a decrease in $T/W_f$, and, thus, a decrease in the values of C and Q on this account. A fiber that has a hydrophilic surface, i.e. has a low value of $\theta$, but also, at the same time, maintains its resiliency in the wet state can be expected to have the characteristics highly suited for applications in absorbent products.

## Results

Two sets of experiments were conducted, in one the webs were bonded by mechanical, and in the other by thermal methods. For the former, needling and hydroentangling processes were used while for the latter, a through - air heating system was employed. The results from these two experiments are discussed separately.

### Mechanically Bonded Structures

A major emphasis was placed on understanding the effects found in webs bonded by needling and hydroentangling, the two methods used most widely for producing absorbent structures. In needling, needles with barbs pass through a bat, prepared either by a carding and cross-lapping procedure or by an air laying method, and entangle the fibers. In the hydroentangling system, water jets from high pressure manifolds impinge at right angles and cause bonding. These procedures, although both mechanical, lead to different structures and, therefore, to different performance in absorbency tests. It was of interest to determine how the webs containing fibers of this study reacted to these processes and what effect the latter had on the absorbency properties. In addition to bonding type and level, other variables involved were the areal density, fiber type, and the web composition. The results are presented in Tables 2 to 5 and illustrated in Figures 5 to 8.

*1. Areal Density*. The results show that the effect of areal density is highly significant. The highest values of the capacity and the rate are obtained in webs of the lowest weight, i.e., 40 $g/m^2$. As the weight increased, the values of the two parameters decreased. In needled structures, the average decrease found in transition from 40 to 120 $g/m^2$ was 19% in capacity and 40% in rate. In hydroentangled structures, the corresponding changes were 25% and 38%. In order to understand the reasons for the effect noted, the values of the fabric final thickness per unit dry mass ($T/W_f$) and the pore size (r) were determined. A summary of the values found in one set of structures, namely, the needled webs of CA and GR (see Table 1).

Accordingly, webs of lower weight, which have higher values of $T/W_f$ and r, are more resilient and compress less when subjected to a given pressure than do webs of higher weight. A higher value of $T/W_f$ should lead to a higher value of the capacity. Since the rate is additionally affected by the magnitude of r, the pore size, similar changes in both $T/W_f$ and r should produce even greater changes in rate than in capacity. These are exactly the results found.

*2. Bonding*. Examining first the results obtained in the needled fabrics, it is seen that the effect of needling is to generally enhance the absorbency performance (Tables 2 and 3 and Figure 5). In all cases, the needled structures (N1 and N2) have higher values of C and Q than do the unneedled materials (N0). Except in three instances (capacities in 100% CA and 33/67 CA/PP and rate in 100% PP), in which the peak values are reached by N1, the lower level of the intensity used (40 needles/$cm^2$), C and Q increased as the intensity increased. The average increases with increase in intensity from 0 to 80 needles/$cm^2$ were 23% in C and 41% in Q.

Such increases have been noted in previous studies [3,6] and attributed to the needling process imparting resiliency to the structure by entangling fibers and creating oriented channels for flow. The fabric resists collapse when subjected to pressure; this leads to an increase in the thickness per unit mass ($T/W_f$) and, therefore, to an increase in the capacity. An increase in $T/W_f$ also causes an increase in pore size, r. The increases in these two parameters together lead to an increase in the rate which, as noted, should be greater than that in the capacity.

In contrast to the results obtained with needling, the wet process involved in hydroentangling produced an adverse effect on absorbency. Generally, the greater the manifold pressures or the specific energy [2] used in entangling, the greater the decrease occurred in C and Q (Tables 4 and 5, Figures 5). It was interesting to note that the webs containing polypropylene did not absorb any fluid at all. In other structures, an increase in the hydroentangling level from H0 to H2 gave a decrease, on an average, of 33% in the capacity and 42% in the rate. As pointed out in a previous paper [7], the changes in C and Q, noted here, are expected to result from the web compacting during the process into a flattened sheet and bonding in that form by hydrogen linkages, if the structure was capable of it. Among the materials used, one could expect that more such bonding will occur in rayon than in cellulose acetate, and the bonding in polypropylene will be little or none. During rewetting, some of the bonds formed were likely to break but the fibers, held in many places, were not expected to resilient back and cause the web, to increase in thickness. Thus, with increase in hydroentangling energy, one could expect that both the values of T/W and r would decrease and lead to a decrease in the values of C and Q.

A comparison of the results obtained on the hydroentangled and the needled fabrics indicate that the values of the absorbency parameters of the latter are significantly greater than those of the former, this difference on an average in the

cellulose acetate/rayon compositions being 28% in the capacity and 66% in the rate. This clearly shows that the structures produced by needling are bulkier and more resilient than those produced by the spunlacing process.

As compared to the values of C and Q of the hydroentangled webs (H1 and H2), those of the control (H0), the structures statically soaked in water and then taken through the spunlacing process without the water jets operating, are significantly greater. On an average, the control, over the hydroentangled, has 33% higher capacity and 42% higher rate. This indicates that the process of wetting, extraction, and drying, through which the control went, produced a structure, which had a better balance of properties in terms of bulk and bonding. The bonds were weaker and fewer; some broke during wetting and led to swelling. In contrast, in the hydroentangled webs (H1 and H2), the fabrics were in a collapsed and dense state and, therefore, the bonds were stronger and more closely spaced. Fewer broke during rewetting and the structure did not resilient back as much.

*3. Fiber Type*. For the effect of fiber type, a summary of results obtained is given in Table 2.

The values represent webs of 100% compositions and averages over different areal densities. Considering first the needled structures, we note that polypropylene has the highest capacity but the lowest rate, whereas rayon has the lowest capacity but the highest rate. The values of cellulose acetate fall in the second position in each case, making it the best overall choice among the three. Comparatively, the capacity of cellulose acetate is 4% lower than that of polypropylene but 17% higher than that of the trilobal rayon. On the other hand, its rate is 18% lower than that of the rayon but 6% higher than that of the polypropylene. These results can be understood by examining the differences that exist in the fibers' wet mechanical and surface energy properties. Capacity is governed by the amount of interstitial space per unit mass, characterized by $T/W_f$. Polypropylene is a fiber that is hydrophobic, does not absorb water into its internal structure, and does not lose modulus when wetting, and, therefore, maintains its air volume for imbibing and holding fluid. Rayon, on the other hand, absorbs substantial amount of water into its internal structure and, therefore, undergoes a substantial drop in its bending rigidity. The web collapses and ends up with a low value of the parameter. Cellulose acetate has a structure that is intermediate to these two materials. It imbibes fluid into its internal structure, but it does so only to a limited extent. Accordingly, its loss of resiliency is relatively small. As clear from the values of $T/W_f$ given earlier, it ends up with greater thickness per unit mass and, therefore, greater capacity, than does rayon.

The order in which the capacities, or $T/W_f$, are ranked should also be roughly the order in which the pore sizes of the materials are ranked. If no factors other than $T/W_f$ and r played a role in determining the rate, then the materials should be ranked in the same order for the rate as they are for the capacity. This is, however, not so in the present case, as the advancing contact angle is not constant but varies among the materials. Contact angle is affected by a number of properties but most strongly by the chemical nature of the surface. Presence of hydrophilic groups in the structure attract water; therefore, the greater the fraction of these groups, the lower the contact angle. The values of this parameter, measured on Soxhlet extracted fibers, were found to be 22°, 54°, and 96°, respectively, for Galaxy rayon, cellulose acetate, and polypropylene. The values, however, could be expected to be smaller if the surface had a finish which is usually applied after manufacturing to make the fiber processable and conducting. The finish on the man-made fibers, especially non-cellulosic, would generally be hydrophilic. Still, it is expected that the ranking of the present fibers with respect to the contact angle would remain the same in the finished as in the finish-free state. Accordingly, of the three materials, rayon has the most hydrophilic and polypropylene the most hydrophobic surfaces. Thus, in spite of the fact that rayon has the lowest values of $T/W_f$ and r, it has the highest value of the rate, and this is because it has the lowest value of $\theta$. Polypropylene, on the other hand, although having the largest values of $T/W_f$ and r, has the lowest rate. This is because the fiber has the largest value of the contact angle.

Considering now the absorbency values obtained in the hydroentangled structures, one sees a largely different picture. Webs composed of polypropylene did not absorb any fluid. In fact, even those fabrics which contained a blend of 33% CA and 66% PP behaved the same way. Among the other two materials, the capacity was higher in CA and the rate higher in GR. Absence of any absorption in polypropylene materials can be understood by realizing that any topically applied finish on its surface, which most likely lowered its contact angle to a value below 90°, will be washed off during the hydroentangling process. Even the control webs of polypropylene, involving statically soaking and then vacuum extracting and drying the material, could be expected to lose the finish. This resulted in the fiber having essentially a non-wettable surface ($\theta > 90°$) and a web composed entirely, or largely, of it having little or no capillary force to imbibe fluid.

The relative behaviors of the cellulose acetate and the Galaxy rayon webs are as expected and explained earlier. An interesting observation to be made is that both the capacity and the rate of the two materials are significantly lower in the hydroentangled than in the needled fabrics. As pointed out earlier, this is because the web collapses during the hydroentangling process and ends up with lower values of $T/W_f$ and r. The percentage decreases in values, when

considering hydroentangled over needled fabrics, are as follows:

| | C | Q |
|---|---|---|
| CA | 19% | 57% |
| GR | 35% | 47% |

A lower decrease in capacity of CA over GR is as expected, i.e., due to a relatively lower loss in resiliency. The decrease in the rate of CA over that of GR is, however, greater. This is most likely due to a relatively greater change (increase) in the contact angle of CA due to the finish washing-off during the hydroentangling process.

*4. Web Composition*. Webs containing 100/0, 67/33, 33/67, and 0/100 compositions of cellulose acetate and rayon, and cellulose acetate and polypropylene were prepared and bonded as discussed earlier. These were characterized for the values of C and Q. The results obtained are illustrated in Figures 6 to 8. (Some results are missing, which are for the structures containing the polypropylene fiber. Two reasons for this are that we fell short of the PP fiber of the specific lot during processing, and some of the hydroentangled webs containing the fiber did not absorb any fluid.)

Considering first the needled structures, one sees that the blended materials gave poorer performance than did the 100% compositions. According to these results, therefore, little was gained by mixing fibers if webs were to be needled. Considering next the hydroentangled structures, it is seen, however, that the blends gave values intermediate to those of the individual components. Furthermore, the changes found were such that near maximum rate could be achieved with only modest loss in capacity if one selected a blend containing larger fraction of CA and smaller fraction of GR. Among the limited number of compositions used, the best mix found was 67/33 CA/GR. However, it is quite feasible that a blend containing even larger fraction of CA (67%<CA<100%) will produce better results. Accordingly, more work is warranted to identify the best composition.

**Thermally Bonded Structures**

In addition to needling and hydroentangling, selected structures were also thermally bonded. Air-laid webs containing two different ratios of a cellulose acetate fiber and a low melt polyester fiber (85/15 and 70/30 CA/PET), were thermally bonded using a through-air system. Drum speed was varied in order to vary the residence time. A summary of results obtained is given in Table 6.

It is seen that with a decrease in drum speed - increase in residence time -, the capacity increased in both structures. The change is about 14% in the 85/15 and 24% in the 70/30 blends. This is most likely due to a fabric becoming more effectively bonded and, therefore, more resilient, with increase in residence time. However, the difference between the average values of C of the two blends is small (70/30 is about 2.4% greater than 85/15), indicating that the presence of additional low melt fiber in the structure did not significantly contribute to an increase in pore volume available for imbibing fluid.

The effects of the drum speed and the blend composition on the rate are most interesting. In contrast to the small effect produced by the fraction of the low melt polymer in the blend on C, its effect on Q is highly significant. The average value of the rate in the 85/15 material is more than twice the rate in the 70/30 blend. Two reasons for the difference noted are that the 85/15 structure as compared to 70/30 has (1) more hydrophilic polymer, and (2) less blocked or interrupted channels for fluid flow. The second observation is substantiated by the effect of drum speed noted on Q. With a decrease in drum speed from 20 to 10 feet/minute, the rate increased by about 19% in the 85/15 blend but decreased by about 21% in the 70/30 material. The most obvious reason for the first result is that bonding and, therefore, resiliency increased. The most plausible reason for the second result is that the extra low melt polymer present in the structure flowed into the pores and partially blocked the channels.

Finally, it would be instructive to compare the results found in the thermally bonded materials with those obtained in the mechanically bonded ones in this research. The comparison brings to light an important observation, which is that the thermally bonded structures when optimized for absorbency performance can have absorbency values that are as good as or perhaps better than those the mechanically bonded structures have. Although very few structures were prepared for the study using the heat bonding system, one of these, i.e. 85/15 composition bonded at 10'/min, has capacity greater than those of the needled and the hydroentangled materials, and rate greater than those of the hydroentangled but smaller than those of only some of the needled materials. One can conclude, therefore, that the thermally bonded nonwovens present excellent potential for applications in absorbent products. Further research can be recommended for exploring these structures and identifying conditions that provide optimum performance.

**Comparison with Theory**

The general trends obtained have been rationalized by considering the effects the materials and the fabric construction factors produced on the values of the three important parameters, namely $T/W_f$, r and $\theta$, that determine the values of the capacity and the rate. However, it would be useful to see how the actual values found compared with those predicted by the models, given earlier. A set of fabrics, namely the needled cellulose acetate materials of different areal densities and levels of bonding, was chosen. The values

of $W_f$ were determined on each specimen prior to GATS tests and those of T from the signals of the LVDTs during the tests. The magnitude of $T/W_f$ was, thus, assessed and plugged in the equation to calculate C. The values of the predicted and the experimentally observed capacities are plotted in Figure 9. Most points are seen to fall closely around the regression line, thus showing a good fit.

The rate of absorbency given by the second model is a more complex parameter and is affected by several factors. However, with 1% saline as the only fluid used, the magnitudes of $\gamma$ and $\eta$ were fixed and known from previous measurements, which were 72.2 dynes/cm and 0.0102 dyes.sec/cm$^2$, respectively. The value of $\theta$, the advancing contact angle, was assessed using a Wilhelmy dynamic contact angle device. For CA, $\theta$ was found to be about 55°. The value of the remaining parameter, r, was estimated using a model published elsewhere [3].

With the values of all parameters known, rate was calculated. The predicted and the experimentally found results are plotted in Figure 10. The fit is excellent with a high value of the correlation coefficient. It is noted, however, that although the trend is well predicted, the predicted rate is several times greater than the experimentally obtained rate. Similar results have been found in the past and the difference in the two rates has been attributed to the differences that exist between the structure on which the model is valid and the structures actually found in webs. The former is characterized by capillaries that are uniform in size and shape and are bound by solid material, and by the material that does not absorb fluid and swell to any extent. In actual webs, however, the capillaries are distorted and are of a variety of shapes and sizes, they are open and not bound by solid material, and the fluid diffuses into and swells the material. All these features tend to slow down the flow of a liquid through the structure and lead to a low value of the rate. However, since the trend is well predicted by the model, one can account for the difference by introducing a factor K, called the "structural constant," in the equation, as done below:

$$Q = Q' / K = [\rho_l \pi r \gamma \cos\theta ] [ T/W_f - 1/A\rho_f ] / 2 \eta K$$

The value of K is given by the ratio of the predicted (Q') to the actual (Q) rate. Its value would be 1 if the structure of a web is ideal, as assumed by Washburn [9], and greater than 1 if there is a difference. Stating it differently, one may assume that the lower the value of K, the closer is the capillary network of the fabric to the ideal.

In our previous studies, the approximate values of K obtained were 11 for blends of a synthetic fiber and regular rayon, 9.6 for Galaxy rayon and 5.5 for cotton. The value found for cellulose acetate in the present study is about 4.8. A lower value of K for CA as compared to those for Galaxy rayon and cotton can be attributed to the cellulose acetate fiber undergoing a relatively less change of volume due to fluid diffusing into its internal structure and a structure containing the fiber undergoing a relatively less distortion of channels when an aqueous fluid contacts the material.

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Table 1. Specifications and Designations Used for Bonded Fabrics

**Needled Structures**

| | |
|---|---|
| N0 | Carded only |
| N1 | Bonded with 40 needles/cm$^2$ |
| N2 | Bonded with 80 needles/cm$^2$ |

**Hydroentangled Structures**

| | | Manifold Pressures (PSI) | | |
|---|---|---|---|---|
| | | Front | Middle | Back |
| H0 | Control | 0 | 0 | 0 |
| H1 | Low | 400 | 600 | 800 |
| H2 | High | 600 | 800 | 1000 |

Table 2. Absorbent Capacity Values, C (g,g), for Needled Structures

| Fabric | Web Wt. | N0 | N1 | N2 | AVG |
|---|---|---|---|---|---|
| Cellulose Acetate 100% | 40 | 18.19 | 22.20 | 21.55 | **20.64** |
| | 80 | 15.24 | 18.19 | 20.44 | **17.96** |
| | 120 | 15.19 | 18.33 | 17.75 | **17.09** |
| **AVG** | | **16.21** | **19.57** | **19.91** | ***18.56*** |
| | | | | | |
| CA/GR 67/33 | 40 | 15.07 | 17.67 | 18.40 | **17.07** |
| | 80 | 13.80 | 15.55 | 16.49 | **15.28** |
| | 120 | 13.22 | 15.53 | 16.18 | **14.98** |
| **AVG** | | **14.03** | **16.25** | **17.02** | ***15.78*** |
| | | | | | |
| CA/GR 33/67 | 40 | 14.80 | 17.91 | 21.69 | **18.13** |
| | 80 | 13.33 | 15.63 | 15.75 | **14.90** |
| | 120 | 12.53 | 13.55 | 15.49 | **13.86** |
| **AVG** | | **13.55** | **15.70** | **17.64** | ***15.63*** |
| | | | | | |
| Galaxy 100% | 40 | 15.16 | 18.12 | 24.39 | **19.22** |
| | 80 | 13.64 | 15.66 | 15.65 | **14.98** |
| | 120 | 12.52 | 13.32 | 14.48 | **13.43** |
| **AVG** | | **13.77** | **15.70** | **18.17** | ***15.88*** |
| | | | | | |
| CA/PP 33/67 | 40 | 16.79 | 20.62 | 20.64 | **19.35** |
| | 80 | 16.34 | 20.27 | 19.75 | **18.79** |
| | 120 | 14.79 | 15.46 | 15.31 | **15.19** |
| **AVG** | | **15.97** | **18.78** | **18.57** | ***17.78*** |
| | | | | | |
| Polypropylene | 40 | 16.87 | 24.92 | 18.95 | **20.25** |
| | 80 | 17.43 | 23.05 | 19.00 | **19.83** |
| | 120 | 16.15 | 18.18 | 19.63 | **17.99** |
| **AVG** | | **16.82** | **22.05** | **19.19** | ***19.36*** |

Table 3. Rate of Absorbency Values, Q (g/g-sec), for Needled Structures

| Fabric | Web Wt. | N0 | N1 | N2 | AVG |
|---|---|---|---|---|---|
| Cellulose Acetate 100% | 40 | 3.44 | 4.32 | 4.54 | **4.10** |
| | 80 | 2.48 | 2.75 | 3.24 | **2.82** |
| | 120 | 2.28 | 2.56 | 2.60 | **2.48** |
| **AVG** | | **2.73** | **3.21** | **3.46** | ***3.13*** |
| | | | | | |
| CA/GR 67/33 | 40 | 2.91 | 3.94 | 4.25 | **3.70** |
| | 80 | 2.01 | 2.64 | 2.63 | **2.43** |
| | 120 | 1.90 | 2.23 | 2.38 | **2.17** |
| **AVG** | | **2.27** | **2.94** | **3.09** | ***2.77*** |
| | | | | | |
| CA/GR 33/67 | 40 | 2.58 | 3.41 | 4.05 | **3.35** |
| | 80 | 1.76 | 2.77 | 2.88 | **2.47** |
| | 120 | 1.23 | 2.07 | 2.39 | **1.89** |
| **AVG** | | **1.86** | **2.75** | **3.11** | ***2.57*** |
| | | | | | |
| Galaxy 100% | 40 | 4.19 | 3.72 | 5.67 | **4.52** |
| | 80 | 3.33 | 4.13 | 5.69 | **4.38** |
| | 120 | 1.50 | 2.44 | 3.55 | **2.50** |
| **AVG** | | **3.01** | **3.43** | **4.97** | ***3.80*** |
| | | | | | |
| CA/PP 33/67 | 40 | 2.64 | 3.57 | 3.93 | **3.38** |
| | 80 | 2.22 | 3.09 | 3.06 | **2.79** |
| | 120 | 1.70 | 1.85 | 2.07 | **1.87** |
| **AVG** | | **2.19** | **2.84** | **3.02** | ***2.68*** |
| | | | | | |
| Polypropylene | 40 | 2.62 | 4.25 | 3.43 | **3.43** |
| | 80 | 2.66 | 3.81 | 2.94 | **3.13** |
| | 120 | 2.01 | 2.02 | 2.75 | **2.26** |
| **AVG** | | **2.43** | **3.36** | **3.04** | ***2.94*** |

Table 4. Absorbent Capacity Values, C (g,g), for Hydroentangled Structures

| Fabric | Web Wt. | H0 | H1 | H2 | AVG |
|---|---|---|---|---|---|
| Cellulose Acetate 100% | 40 | 21.46 | 15.55 | 16.66 | **17.89** |
| | 80 | 19.33 | 11.81 | 11.37 | **14.17** |
| | 120 | 17.70 | 11.94 | 10.39 | **13.34** |
| **AVG** | | **19.50** | **13.10** | **12.81** | ***15.13*** |
| | | | | | |
| CA/GR 67/33 | 40 | 17.61 | 14.92 | 15.21 | **15.91** |
| | 80 | 16.12 | 9.85 | 8.95 | **11.64** |
| | 120 | 16.11 | 10.04 | 8.60 | **11.58** |
| **AVG** | | **16.61** | **11.60** | **10.92** | ***13.04*** |
| | | | | | |
| CA/GR 33/67 | 40 | 15.59 | 13.19 | 10.70 | **13.16** |
| | 80 | 14.68 | 9.65 | 7.95 | **10.76** |
| | 120 | 13.68 | 9.12 | 8.38 | **10.39** |
| **AVG** | | **14.65** | **10.65** | **9.01** | ***11.44*** |
| | | | | | |
| Galaxy 100% | 40 | 13.84 | 11.21 | 12.08 | **12.38** |
| | 80 | 12.66 | 9.09 | 9.26 | **10.34** |
| | 120 | 12.55 | | | |
| **AVG** | | **13.02** | **9.77*** | **10.17*** | ***10.99**** |
| | | | | | |
| CA/PP 33/67 | 40 | | | | |
| | 80 | | | | |
| | 120 | | | | |
| **AVG** | | | | | |
| | | | | | |
| Polypropylene | 40 | | | | |
| | 80 | | | | |
| | 120 | | | | |
| **AVG** | | | | | |

*Extrapolated due to missing numbers.

Table 5. Rate of Absorbency Values, Q (g/g-sec), for Hydroentangled Structures

| Fabric | Web Wt. | H0 | H1 | H2 | AVG |
|---|---|---|---|---|---|
| Cellulose Acetate 100% | 40 | 1.79 | 1.56 | 1.71 | **1.69** |
| | 80 | 1.74 | 1.1 | 1.01 | **1.28** |
| | 120 | 1.48 | 0.95 | 0.86 | **1.10** |
| **AVG** | | **1.67** | **1.20** | **1.19** | ***1.36*** |
| | | | | | |
| CA/GR 67/33 | 40 | 3.46 | 2.69 | 1.38 | **2.51** |
| | 80 | 2.62 | 1.52 | 1.38 | **1.84** |
| | 120 | 2.41 | 1.54 | 1.2 | **1.72** |
| **AVG** | | **2.83** | **1.92** | **1.32** | ***2.02*** |
| | | | | | |
| CA/GR 33/67 | 40 | 3.27 | 2.38 | 1.84 | **2.5** |
| | 80 | 2.69 | 1.59 | 1.09 | **1.79** |
| | 120 | 1.69 | 1.29 | 1.02 | **1.33** |
| **AVG** | | **2.55** | **1.75** | **1.32** | ***1.87*** |
| | | | | | |
| Galaxy 100% | 40 | 2.98 | 2.57 | 2.18 | **2.58** |
| | 80 | 2.44 | 1.74 | 1.38 | **1.85** |
| | 120 | 2.15 | | | |
| **AVG** | | **2.52** | **1.96*** | **1.59*** | ***2.02**** |
| | | | | | |
| CA/PP 33/67 | 40 | | | | |
| | 80 | | | | |
| | 120 | | | | |
| **AVG** | | | | | |
| | | | | | |
| Polypropylene | 40 | | | | |
| | 80 | | | | |
| | 120 | | | | |
| **AVG** | | | | | |

*Extrapolated due to missing numbers.

Table 6. Absorbency Properties of Through-Air Thermally Bonded Structures Containing Cellulose Acetate and Low Melt Polyester Fibers

| **Fabric** | **Drum Speed** (Ft/min) | **C** (g/g) | **Q** (g/g-sec) |
|---|---|---|---|
| **CA/PET(LM)** | | | |
| 85/15 | 10 | 23.7 | 3.12 |
| | 15 | 22.0 | 2.91 |
| | 20 | 20.7 | 2.63 |
| | | | |
| 70/30 | 10 | 24.7 | 1.07 |
| | 15 | 23.3 | 1.33 |
| | 20 | 20.0 | 1.36 |
| | | | |

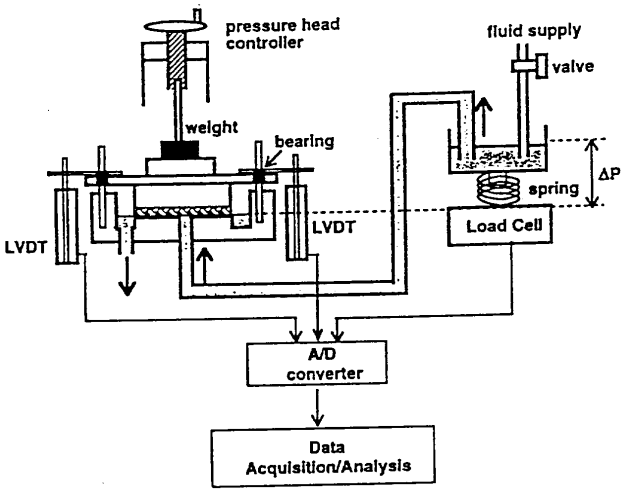


Figure 1. Device for Characterizing Absorbency

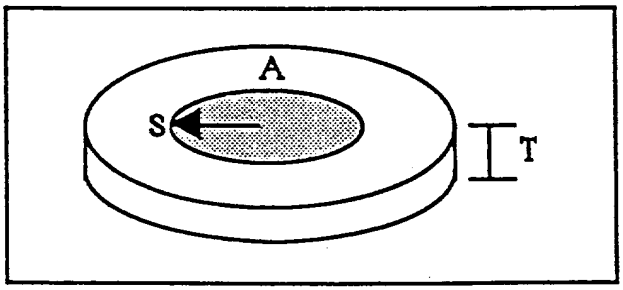


Figure 2. Wet Element

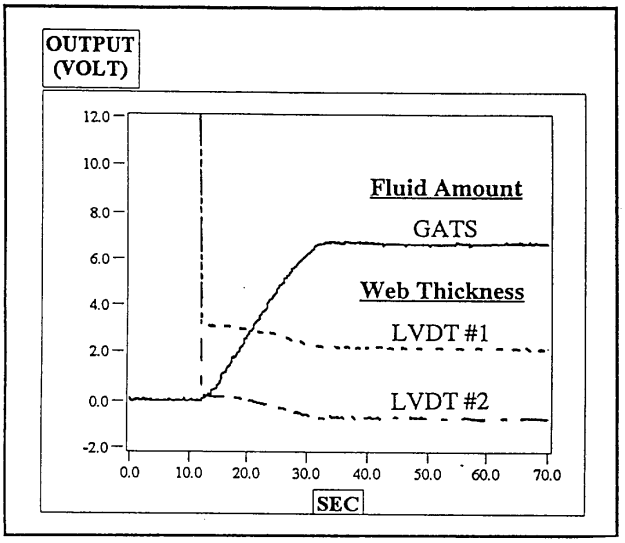


Figure 3. Typical Absorbency Curve on Computer Monitor

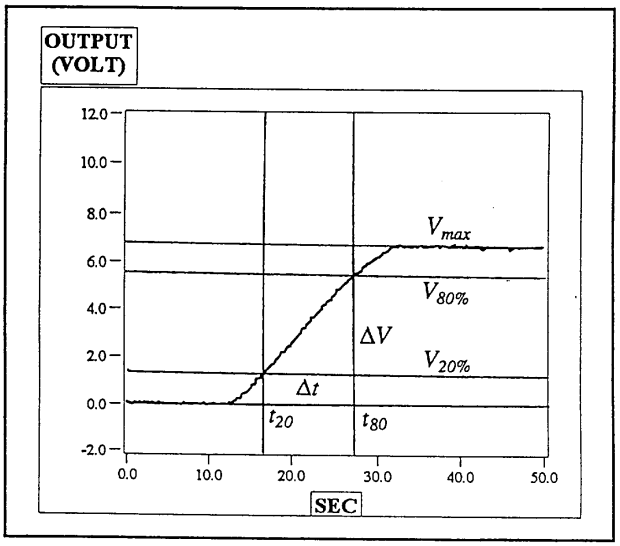


Figure 4. Measurement of Capacity and Rate

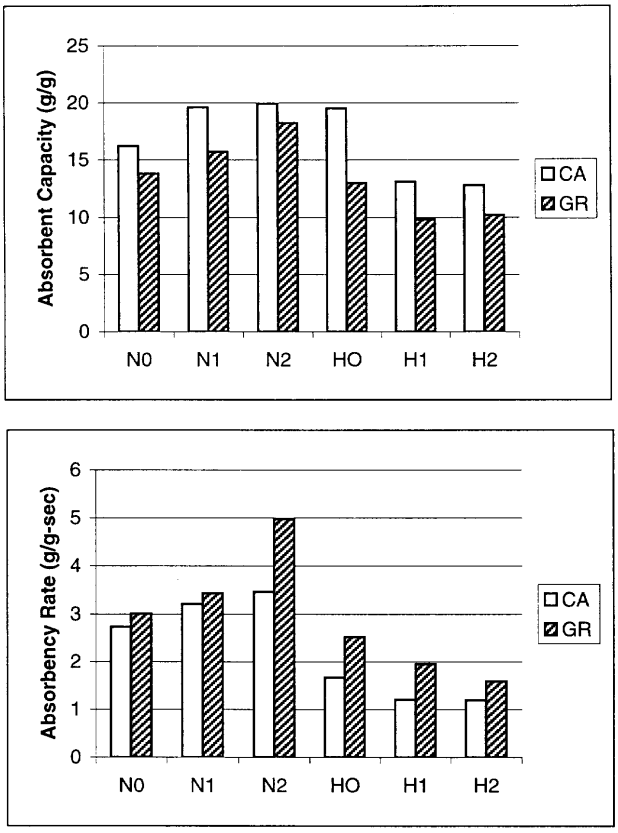


Figure 5. Effect of Needling and Hydrentangling on Absorbency in Cellulose Acetate and Galaxy Rayon Structures. (Values averaged over all areal densities.)

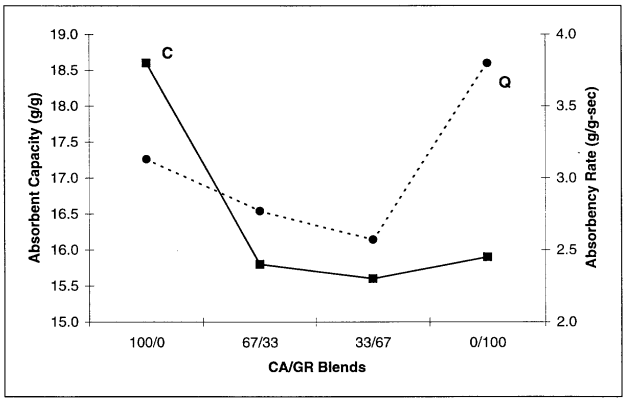


Figure 6. Effect of Blend Ratio on Absorbency Values in Needled Strictures of Cellulose Acetate and Galaxy Rayon

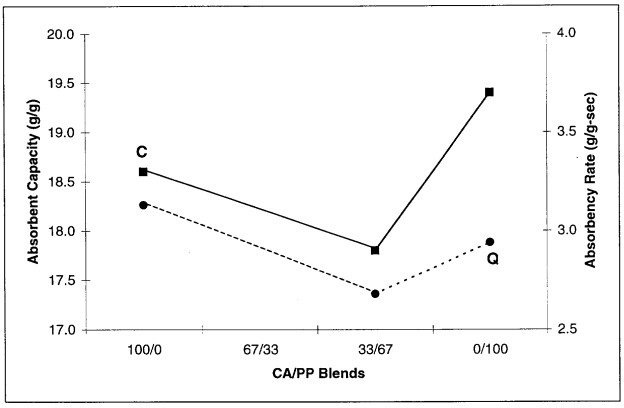


Figure 7. Effect of Blend Ratio on Absorbency Values in Needled Structures of Cellulose Acetate and Polypropylene

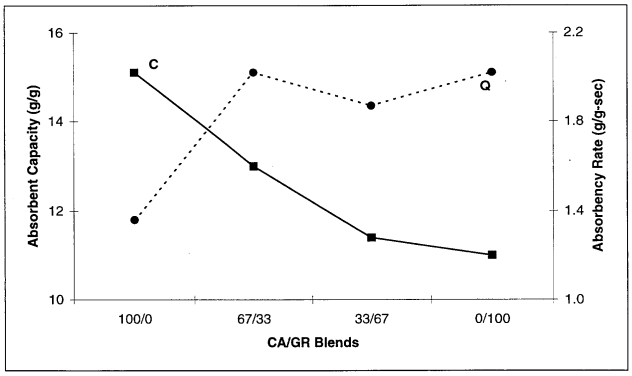


Figure 8. Effect of Blend Ratio on Absorbency Values in Hydroentangled Structures of Cellulose Acetate and Galaxy Rayon

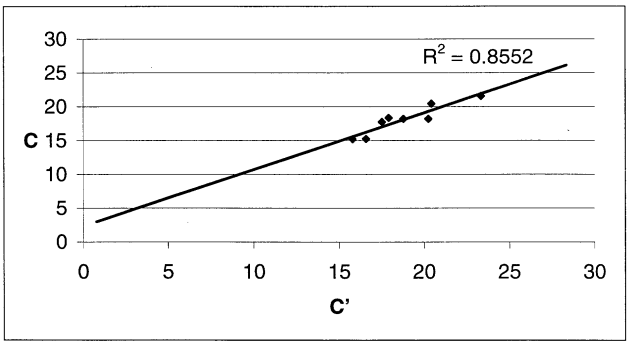


Figure 9. Correlation Between Measured (C) and Predicted (C') Values of Capacity in Needled Cellulose Acetate Structures. (The data includes different areal densities and needling intensities.)

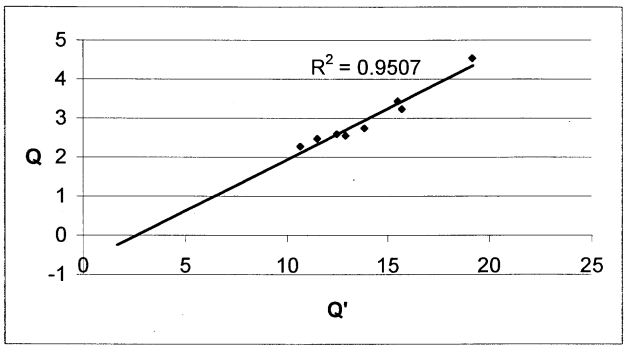


Figure 10. Correlation Between Measured (Q) and Predicted (Q') Values of the Rate in Needled Cellulose Acetate Structures. (The data includes different areal densities and needling intensities.)