Effect of water pressure on absorbency of hydroentangled greige cotton non-woven fabrics

Paul Sawhney, Chuck Allen, Michael Reynolds, Brian Condon and Ryan Slopek

Abstract
A greige (non-bleached) cotton lint was used to fabricate non-woven fabrics on a Fleissner MiniJet, using different water pressures for the fiber entanglements. The greige cotton and its hydroentangled non-woven fabrics were primarily tested for their hexane extracts (waxes) and water-soluble (sugars) contents using the AATCC TM97 Standard Extraction Test. Tests have shown that a water pressure of 125 Bar or higher almost totally removed the greige cotton’s inherent hydrophobic waxes and water-soluble sugars. This discovery is a significant milestone in the development of greige cotton-based non-wovens because it could change the greige cotton’s native hydrophobic character into a desirable hydrophilic character for many end-uses. In fact, the AATCC Test Method 79-2007 has confirmed that the greige cotton non-wovens fabricated with high water pressure of 125 Bar are absorbent, as indicated by the 1-second time or less it took for the water drop to completely diffuse onto the fabric surface.

Keywords
absorbent non-wovens, greige cotton lint, hydroentangled

Generally, cotton bleached in fiber form (mostly in the form of ginning motes, linters and textile processing wastes (comber noils, card strips, etc.) and mostly in blends with manufactured staple fibers, such as polypropylene, polyester, rayon, etc.) has been used until now to produce non-woven fabric structures for certain medical, hygienic and wiping end-uses. 1 These products are attractively marketed and sold, using Cotton Incorporated’s popular cotton logo/trademark (with the word “ENHANCED” printed beneath the logo) on non-woven products containing at least 15% cotton (Logo ). The registered trademark of Cotton Incorporated, 6399 Weston Parkway, Cary, NC. 27513). However, today, very little regular (classical) greige (non-bleached) cotton lint or, for that matter, even the bleached cotton lint (in the fiber form, before it is processed into non-woven fabrics) is used by US non-woven fabric manufacturing companies.2 3 This discovery of making greige (non-bleached/ hydrophobic) cotton fiber into a hydrophilic cotton non-woven fabric, via the fiber hydroentangling process at certain specified metrics and conditions, may eliminate the traditional process of scouring. For certain end-use applications, perhaps the bleaching process may also be eliminated, provided a mechanically pre-cleaned cotton of satisfactory whiteness can be selected as the raw material.4

Cotton Chemistry and Utilization Research Unit, SRRC-ARS-USDA, USA.
The Southern Regional Research Center is a federal research facility of the US Department of Agriculture in New Orleans, LA, USA.
The names of the companies and/or their products are mentioned solely for the purpose of providing information and do not in any way imply their endorsements by the USDA over others.

Corresponding author:
A Paul Singh Sawhney, Cotton Chemistry and Utilization Research Unit, SRRC-ARS-USDA, 1100 Robert E. Lee Blvd. New Orleans, LA, 70124, USA
Email: ap.singh@ars.usda.gov
Materials and methods

A bale of commercially available pre-cleaned American Upland greige cotton lint was selected for the study. The fiber quality was determined by Advanced Fiber Information System (AFIS, USTER® AFIS PRO, Uster Technologies, Inc., Charlotte, NC, USA). The cotton was processed under mill-like conditions on the Center’s commercial-grade fiber opening and cleaning line (hopper, step cleaner and fine opener) and chute fed to a Crosrol Mark IV card, which, in this study, delivered a web of approximately 12 g/m².[5] The web, via a conveyor belt, was transported to a commercial cross-lapper, which, in turn, fed the multi-lapped material to a double-board (one with a down stroke and the other with an upstroke of needles) needlepunch machine for light needling. The needling impact was attained by 3-barb, conical needles (Foster Needle Co., now, a subsidiary of Groz – Beckert, KG, Manitowoc, WI, USA) that were 9 cm in length (Part# 5240150). The needlepunched substrates (approximately 70 g/m²) were subjected to hydroentangling water jets on a 1-m wide commercial hydroentangling system (Figure 1) to produce non-woven fabrics at various water pressures (at the low-pressure head for pre-wetting and the two high-pressure heads for hydroentangling (bonding) the non-bonded fibrous material). The line production speed was kept constant in this study. The fabrics were dried in an online gas-fired, through-air drum dryer before being wound on to a roll at the end of the production line. The fabrics primarily were tested for the hexane and water-soluble extractable(s) and water absorbency, although some physical and mechanical characteristics were also determined using commonly used ASTM and AATCC standard test methods, procedures and conditions. Where applicable, the standard statistical tools, such as averages, standard deviation, coefficient of variation, etc., were used to ensure reliability of the data and determine significance of the results obtained.

AATCC Method 97-2009 “Extractable Content of Textiles” was used to measure the water-soluble and hexane-extractable matters in the fabrics. In this method, the fabric sample is dried to a constant weight. Then, it is placed in a beaker with 200 ml of 82 ± 3°C deionized water for 2 hours. The fabric and water are poured into a sieve and rinsed twice, each time with 100 ml of deionized water at 82°C. The sample is dried again to constant weight. The amount of water-extractable matter is calculated, as a percentage of the fabric weight, using the difference in the weight of the fabric sample before and after the above stated water treatment. Using the same fabric that was used for the water extraction, it is dried to a constant weight. The hexane-extracted matter is determined, again as a percentage of the fabric, using the weight difference before and after the hexane extraction.

AATCC Method 79-2009 “Absorbency of Bleached Textiles” was used to measure the absorbency of the various fabrics. In this method, the fabric sample is conditioned at standard textile testing conditions for 24 hours. The fabric is then mounted in a 6-inch or more diameter embroidery hoop so that the fabric surface is free of wrinkles. The hoop is placed 1.0 ± 0.1 cm below the tip of a burette and one drop of deionized...
water at 21 ± 3°C is allowed to fall onto the fabric. Using a stop watch the time required for the surface of the liquid to lose its specular reflectance (sheen) is measured. The test is stopped at 60 seconds even if the drop is not absorbed.

The hydraulic energy that the water jets (at different water pressures on various heads) applied to the lightly needled fibrous web(s) to form the fabric(s) was calculated by the following formula supplied by Fleissner, the manufacturer of the hydroentanglement system used:8

\[ E = K(C_d^2NP_3/2/ WS), \]

where: \( E \) is the hydraulic energy in hp-hr/lb of fabric, \( K \) is a constant (0.005375) for the units used, which includes the orifice coefficient, \( C \) is the working width of jet strip (1 m), \( d \) is the orifice diameter in mm of the jet strip (0.12 mm), \( N \) is the number of orifices per inch (40/inch), \( P \) is the pressure in psi, \( W \) is the web weight in g/m², and \( S \) is the fabric production/line speed (m/min).

It may be noted that the unit-less constant \( K \) in the above formula includes the orifice discharge coefficient that undoubtedly is critical and must be taken into account in calculating the hydraulic energy delivered. The “\( C \)” and “\( d \)” in the formula are separate metrics (with their own respective units of measurements) and they respectively denote the working width of the jet strip and the orifice diameter (which shows as \( d^2 \) in the formula). Thus, the energy value(s) shown in Table 2 is a sum of the energies applied from all the three jet strips utilized in the production of the fabrics, using the specified process metrics and water pressures.

### Results and discussion

Table 1 shows the quality characteristics of the pre-cleaned cotton used in the study. As seen, the cotton is exceptionally clean, although the other values somewhat are marginal of a typical Upland cotton.

Table 2 shows the hexane and water-soluble extracts (contents) and absorbencies of the (pre- and post-hydroentanglement) fabrics hydroentangled at different water pressures and, hence, energy levels. As seen, the greige base (control) material, i.e., without the water impact, was detected to have its wax content of ~0.28% (by weight). When the same material was impacted by the system’s (common) low water pressure (LP) of 50 Bar at the pre-wetting jet head and high water pressure of 125 Bar, or higher, at the two high-pressure (HP) hydroentangling (fabric forming) jet heads, its wax content was reduced to ~0.03%, resulting in excellent absorbency (without the traditional scouring). The exact mechanism of occurrence of this unique phenomenon is currently not well understood. However, the previous, preliminary work done at the Center had shown that the hydraulic/mechanical energy at certain levels removed, either partly or fully, the lower molecular-weight \( C_{16, 18...} \) hydrocarbons (waxes) and especially left the cotton fiber’s pectin content almost unaffected.9 In-house staining of the hydroentangled cotton fabrics listed in Table 2 with Ruthenium Red confirmed the presence of pectin in all samples. In any event, based on the data summarized in Table 2, the probability of the (greige cotton) fabric hydroentangled at or above 125 Bar of water pressure to be hydrophilic is unity, and, conversely, the probability of the fabric hydroentangled below a pressure of 100 Bar being hydrophilic approaches 0. It is important to note, however, that the probability of a hydroentangled greige cotton fabric being hydrophilic or hydrophobic is ultimately dependent on multiple parameters in addition to pressure, such as density of the web, temperature and chemistry of the water, line speed, and, above all, the quality of cotton with regard to its foreign matter (non-cellulosic) content.

The stated water pressures at the three jet heads together delivered (calculated) hydraulic energy of 1.54 hp-hr/lb of fabric. Although the fabric production speed in this study was low as compared to the commercial standards, it is conjectured that the hydroentanglement of greige cotton, even at higher production speeds (and, consequently, at relatively lower energy levels at the same water pressures) will at least partly remove the greige cotton’s natural waxes and water-soluble matter. Beside the line production speed, the fabric type and density (basis weight) may also influence the effective impact of the delivered hydraulic energy.

### Table 1. Fiber quality of the supplied cotton (AFIS data)

<table>
<thead>
<tr>
<th>Sample origin</th>
<th>Nep count (g)</th>
<th>Length based on weight or L(w) (in)</th>
<th>Upper quartile length L(w) (in)</th>
<th>Short fiber content based on L(w) (%)</th>
<th>Length based on number or L(n) (in)</th>
<th>Short fiber content based on L(n) (%)</th>
<th>Trash count (g)</th>
<th>Dust count (g)</th>
<th>Maturity ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bale</td>
<td>178</td>
<td>0.92</td>
<td>35.8</td>
<td>1.13</td>
<td>10.8</td>
<td>0.74</td>
<td>49.9</td>
<td>28.8</td>
<td>1</td>
</tr>
</tbody>
</table>
energy. It may be mentioned that the industrial utilization of bleached cotton in blends with some manufactured staple fibers generally does not involve very high water pressures or energy levels. Typically, the HP is 90 Bar or below, but the industry does use several HP heads in series to increase productivity. It may also be worthwhile to mention here that cotton is an agricultural commodity and, therefore, depending on many factors and variables such as the weather, cultivar, growth area/time, seed, etc., it may contain different levels of waxes and other impurities on its fibers. Obviously, the water pressure/energy required to remove the hydrophobic matter (waxes) of different quality cottons may vary considerably, in addition to any variations induced or influenced by the line production speed and the web/fabric basis weight and form. However, the hydroentangling water pressure/energy still remains a vital factor that affects the hexane extraction and ultimately determines the hydrophilicity and absorbency of the resulting fabric.

The results of our several investigations and recalculations have confirmed that, under the specific processing metrics and conditions involved, the water pressures of 125 Bar at the two HP heads (and the common 50 Bar at the LP head) deliver a calculated total hydraulic energy of 1.54 hp-hr/lb to a density fabric and remove almost all of the greige cotton’s impurities that traditionally are removed by a chemical scouring process. Indeed, this is an interesting finding and a significant research accomplishment in that certain hydraulic pressure/energy levels in a cotton hydroentangling process can make a naturally hydrophobic greige cotton fiber/fabric into a hydrophilic/absorbent fabric without the costly, cumbersome and environmentally sensitive chemical process of scouring. This significant milestone may be particularly useful in the development of economical greige cotton-based non-woven fabrics for certain end-use applications. However, if bleaching is necessary, these greige cotton fabrics may be efficiently bleached without the customary scouring process.

Table 3 shows the physical and mechanical properties of the greige cotton non-woven fabrics produced. As seen, the fabric thickness decreases with increasing water pressure and, much like the absorbency, it is dependent on the water pressure. Increasing the pressure of the high pressure heads from 90 to 175 Bar, decreases the thickness by 1/10 of a mm, but the tensile strength increases in machine direction (MD) and stays nearly constant in cross-direction (CD). The underlying reason for the noted trends or behaviors of the MD and CD tensile strengths probably lies in the (initial) aligned orientation of fibers in the MD of the card web produced and used, as the card had no randomizer roll installed. As a crosslapper had to be used to produce a multi-layered batt of approximately 70 g/m² in order to meet the fabric target weight of 70 g/m², it almost totally changed the fibers’ orientation/alignment to the machine CD. In other words, most fibers in the batt used for hydroentangling essentially ended up aligning in the CD, which consistently impacted the resulting fabric’s CD strength. However, the formation of seemingly strong, yarn-like, bunched fibrous structures (corresponding to the water jets from the high pressure jet strips), observed in the fabric’s MD, probably contributed favorably towards the fabric’s MD strength, depending on the intensity of the water pressure. At any rate, the various metrics in Table 3 are well within the expected and normal values for cotton-based non-wovens. It may be noted that cotton lint, as mentioned previously, has been rarely used, if any, in commercially hydroentangled non-woven fabrics.

<table>
<thead>
<tr>
<th>Water pressure (Bar)</th>
<th>Hydraulic energy applied to web (hp-hr/lb of fabric)</th>
<th>Hexane-extractables (%)</th>
<th>Percent of hexane-extractables removed (%)</th>
<th>Water-solubles (%)</th>
<th>Percent of water-solubles removed (%)</th>
<th>Absorbency drop test (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/0/0</td>
<td>0</td>
<td>0.28</td>
<td>0</td>
<td>2.10</td>
<td>0</td>
<td>60+</td>
</tr>
<tr>
<td>50/90/90</td>
<td>1.01</td>
<td>0.10</td>
<td>64.3</td>
<td>0.49</td>
<td>76.7</td>
<td>60+</td>
</tr>
<tr>
<td>50/100/100</td>
<td>1.15</td>
<td>0.09</td>
<td>67.9</td>
<td>0.52</td>
<td>75.2</td>
<td>27</td>
</tr>
<tr>
<td>50/110/110</td>
<td>1.30</td>
<td>0.10</td>
<td>64.3</td>
<td>0.43</td>
<td>79.5</td>
<td>12</td>
</tr>
<tr>
<td>50/120/120</td>
<td>1.46</td>
<td>0.11</td>
<td>60.7</td>
<td>0.48</td>
<td>77.1</td>
<td>6.6</td>
</tr>
<tr>
<td>50/125/125</td>
<td>1.54</td>
<td>0.03</td>
<td>89.3</td>
<td>0.50</td>
<td>76.2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>50/150/150</td>
<td>1.97</td>
<td>0.04</td>
<td>85.7</td>
<td>0.46</td>
<td>78.1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>50/175/175</td>
<td>2.44</td>
<td>0.03</td>
<td>89.3</td>
<td>0.16</td>
<td>92.4</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

*aOn the two high pressure (HP) jet heads (with a common pre-wetting pressure of 50 Bar at the low-pressure (LP) head). bBy weight of the cotton substrate.
However, the Agricultural Research Service of the US Department of Agriculture has now produced and tested, in the past 2 years or so, thousands of yards of non-woven fabrics made with 100% cotton lint at their Southern Regional Research Center in New Orleans. These fabric properties reported in Table 3 are comparable with the equivalents obtained in the previous studies.1,5

### Conclusion

The hydroentanglement system of producing non-woven fabrics from staple fibers is one of the most efficient and popular processes today. However, its application for cotton has been limited for certain viable reasons, including cotton’s lack of cleanliness and its naturally hydrophobic character, which, in the existing non-wovens industry, generally requires scoured and bleached cotton in fiber form. The scouring and bleaching of cotton in fiber form is costly, cumbersome, and environmentally sensitive and, furthermore, makes the bleached fiber difficult to mechanically process. A study conducted with a mechanically pre-cleaned greige cotton, using a hydroentanglement system for producing non-woven fabric structures, has shown that, by using relatively higher than normal hydroentangling pressures/energies, a (gin) pre-cleaned greige (naturally hydrophobic) cotton indeed can be successfully converted into non-woven fabrics that are clean and hydrophilic. These products may not require the traditional cotton scouring (and possibly bleaching) process to attain the desired fabric absorbency that is so critical for many downstream processes including bleaching, dyeing, and/or any special finishing of cotton fabrics. From the economic point of view, it is estimated that a use of mechanically pre-cleaned greige cotton instead of a customary scoured and bleached cotton fiber could save at least $0.50/lb for a 100% cotton non-woven fabric produced. This is based on the fact that, under a normal business climate, bleached cotton typically sells for about twice the price of its virgin greige version.

### Acknowledgments

The authors would like to thank the Agricultural Research Service of the US Department of Agriculture for providing all the necessary resources to conduct and report this fascinating research.

### References

2. Hedge RR, Kamath MG and Dahiya A. *Fiber and fiber consumption in nonwovens*. 2004; MSE 554. UT.
4. US Department of Agriculture, Agricultural Research Service, Southern Regional Research Center, *Cotton


