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Advent of Greige Cotton Non-Wovens Made using a Hydro-Entanglement Process

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Abstract Using greige (scour/bleach-less) cotton, non-woven fabrics have been successfully produced by adopting conventional fiber opening, cleaning and (modified) carding machines followed by cross-lapping, pre/light needling, and hydro-entanglement (H-E) on modern commercial machinery and equipment. Using standard test methods and procedures, the fabrics were evaluated for their weight, thickness, burst strength, tensile and tear failures in both machine (MD) and cross (CD) directions, and absorbency. Dimensional characteristics of the fabrics were determined before and after an ordinary wash. Microscopic examinations of the fiber/fabric surfaces before and after various conditions/degrees of H-E were conducted. Results of these preliminary research investigations have shown that a run-of-the-mill greige cotton, processed on a conventional cotton cleaning and preparatory system, can indeed be efficiently processed on the downstream non-wovens production equipment. In addition, it has been shown that different processing conditions, especially the high-pressure (HP) hydraulic energy of the H-E system, have a considerable influence on properties of the fabrics produced. At the nominal fabric production rates deployed in the research trials, pressure greater than 100 bar (at the system's two HP jet-heads) produces a fabric that is partially hydrophilic: a desirable attribute for many end-use applications of cotton non-wovens. Based on a previous in-house investigation, it seems that the HP (hydraulic energy) at certain levels partly removes some of the greige cotton fiber's natural hydrophobic defensive membrane (outer-surface barrier) of heavy hydrocarbons, such as waxes, pectins, etc., thus making the fiber/fabric partially hydrophilic. Further, it has been observed that the high water pressures (HP), under otherwise similar processing conditions, tend to fracture some cotton fibers into tiny fibrils, as evidenced by scanning electron microscopy (SEM) images. These ruptured fibers, by way of exposing their inner (hydrophilic) walls, could also partly contribute to the fabric's improved absorbency at elevated hydraulic energy levels. Furthermore, a rather unique fabric structure, comprising certain well-defined fibrous *"strands and channels,"* observed at elevated (HP) pressures is also deemed to partly contribute to the greige fabric's improved wickability.

Key words greige cotton nonwovens, hydro-entangling process, needle-punch, fabric absorbency and wick-ability, SEM images of hydro-entangled cotton fibers

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Figures 1, 2 appear in color online: http://trj.sagepub.com

Introduction

Commercially produced non-woven textiles have been in vogue for several decades and currently are growing at promising rates worldwide [1]. However, today's non-wovens are mostly made of manufactured polymeric fibers, such as polypropylene, polyester, polyethylene, rayon and the like [2]. The use of cotton in the non-wovens sector has been limited mainly because of economics and certain technical factors in context with the prevailing end-use products [3]. Most of the cotton fiber ever used in the non-wovens sector predominantly has been bleached cotton, especially for medical end-use applications [4]. Bleached cotton is relatively expensive, difficult to process, and environmentally sensitive [5]. The problem with the use of greige cotton is that it requires substantial cleaning of its foreign and contaminating matter, which consequently requires specialized processing equipment and technical expertise that the existing non-wovens companies generally do not have in their plants [6].

The U.S. Department of Agriculture wants to increase value-added utilization of cotton, a significant cash crop. The National Program Staff of the Agricultural Research Service, USDA, and the national cotton industry leaders have directed the Cotton Chemistry and Utilization Research Unit (CC&U RU) at the Southern Regional Research Center to explore research avenue(s) to increase the use of cotton in non-wovens. Accordingly, the Unit recently has established a new and elaborate (perhaps, one of a kind in the world) Cotton Nonwovens Research Laboratory & Pilot Facility. The Unit has purchased a significant quantity of state-of-the-art machinery and equipment for conducting basic and applied research to develop new technologies to incorporate cotton into existing and new non-woven products. In addition to modification of an existing cotton (tandem) card to produce a web of cotton fibers instead of a sliver, the new machinery includes a cross lapper, a pre-needle-punch machine, a hydro-entanglement (H-E) system [7], water purification system and (possibly and shortly) a high-production non-wovens card. In addition, the new non-wovens laboratory now has almost all types of lab-scale textile bathing, padding, curing, drying, coating and special-finishing equipment for any kind of conventional chemical finishing and for any special chemical treatments for function-specific finishing of textiles [8]. A wide variety of test instruments are also available to assess resulting products of the research efforts.

A preliminary research study was undertaken to investigate the processing of regular greige cotton on the newly installed machinery and equipment for fabricating certain non-woven fabric structures. Recent research in the area of non-wovens has resulted in a greater understanding of the needle punch process, ultimately leading to the development of novel light-weight needle punched composites [9–11]. In the work presented here, lightly pre-needled condensed webs of greige cotton fiber were produced on commercial-grade needle punch equipment and under standard conditions and used to investigate the H-E process of fabricating non-wovens. This article briefly describes the various processes and procedures involved in the production and evaluation of greige cotton-based non-woven fabrics, with a special emphasis on the H-E system and particularly on the effects of some of its processing parameters (e.g. hydraulic energy and production speed) on the properties and characteristics of the non-woven fabrics produced.

Methods and Procedures

Two randomly selected bales of American Upland cottons were procured for this study. The fiber quality of the bales was determined by AFIS. The cotton stock from each bale was processed under mill-like conditions on the Center's (commercial) fiber opening and cleaning line and chute fed to a Crosrol, Mark IV cotton tandem card, which had been modified to deliver a consolidated web of approximately 10 g/m^2. The web, via a conveyor belt, was transported to a commercial cross-lapper for producing a multi-lap assembly, which was fed to a double-board, pre-needling machine for a light needling impact by 3-barb needles that were 9 cm in length [12, 13]. The needle-punched substrates were subjected to H-E on a 1-m wide commercial H-E system (Figure 1) to produce a number of 100% greige cotton non-woven fabrics (as shown in Figure 2) at varied water-jet pressures (both, at the low-pressure (LP) head for pre-wetting the web and at the two high-pressure (HP) heads for the fiber entanglements). The fabric production rate was kept nominal, ranging from 5 to 25 m/min for different trials. The fabrics were dried in an online, gas-fired, hot-air chamber, before being wound onto a paper tube at the end of the H-E line. To examine the dimensional stability of the non-woven fabrics, 1 m^2 sections were cut from each run and the greige fabrics were washed, and subsequently dried, using All™ detergent and warm water. All of the fabrics produced were tested, at the Center, for their important mechanical and physical properties and characteristics, using the following standard test methods and procedures, as applicable [14,15].

- Linear density: ASTM D3776-87.
- Thickness: ASTM D5729-97.
- Tensile strength and failure-elongation: ASTM D5035-95.
- Tear strength: ASTM D5735-95.
- Bursting strength: ASTM D3786-87.
- Absorbency: Drop Test – AATCC TM 79-2000 and Wicking Test – AATCC Committee RA63.
- Microscopic surface examination: AATCC TM 20-2005.

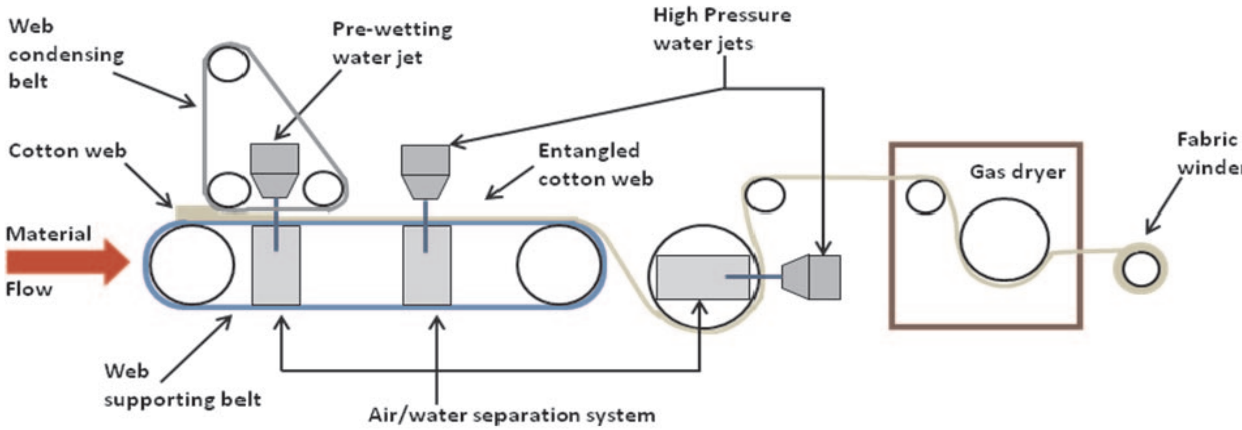

Figure 1 Schematic diagram of the commercial hydro-entanglement process used in the study.

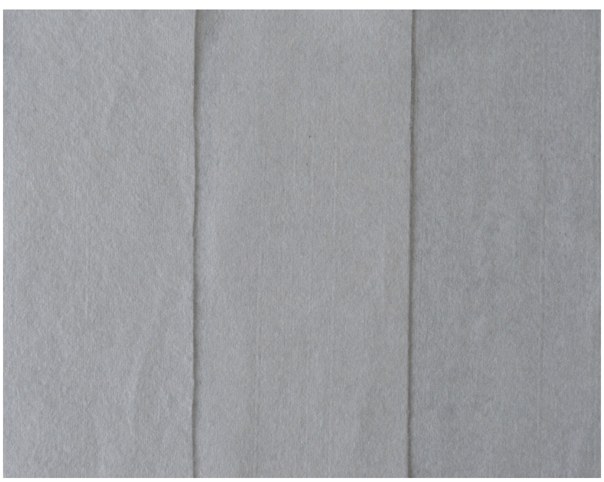

Figure 2 Appearance uniformity of a greige cotton non-woven fabric made by hydro-entanglement process.

- Dimensional characteristics: Objective measurements of standard-cut samples, using a ruler and AATCC TM 135-2004.

Results and Discussion

Table 1 shows the fiber quality characteristics of the two cotton bales used in the study. As can be seen, both bales exhibit similar measurements of fiber length. Bale #2 is slightly cleaner than Bale #1. The amount of trash and dust of both stocks is reduced with each step of the fiber opening/cleaning process. The trash in Bale #1 is reduced by 51% in the opening process and by a total of 92% upon carding. The cleaning and carding of Bale # 2 removed nearly 94% of the trash originally present in the bale. Although the data of Table 1 clearly show that the deployed opening, cleaning and carding processes effectively processed the greige cotton fibers, a slight increase in the short fiber content and, consequently, a slight decrease in the fiber length of the carded stocks of both bales can be observed, as expected. The fiber length and short fiber content of cotton are critical in the traditional (spinning and weaving) textile processing, but their significance in the cotton non-wovens processing and products is yet unknown. Studies to determine the effects of cotton fiber length, short fiber content, and other properties on the non-wovens processes and products are underway.

To examine the effects of H-E process parameters, namely the HP and LP, on the mechanical and physical properties of the non-woven fabrics, several small-scale trials were conducted using the carded greige cotton materials (webs) that had under gone cross-lapping and light pre-needling. The first trial was performed using a cotton web that essentially had been cross-lapped five times and lightly needled before being hydro-entangled at various HPs. In this study, the pre-wetting LP was held constant at 30 bar and the H-E pressure (HP) was varied from 50 to 200 bar. Table 2 outlines the mechanical properties of the fabrics in both the machine (MD) and cross (CD) directions.

The data in Table 2 show that increasing the HP increases the tensile strength of the fabric in both MD and CD directions, although an early maxima of tensile strength in the cross direction is reached at a HP of 75 bar. The tensile strength in both directions appears to reach a plateau at a HP of 150 bar before slightly decreasing. Pressures above 200 bar were not examined due to safety concerns and equipment limitations. Initially, as seen, the tensile strength in the cross direction is greater than that in the

Table 1 Fiber characteristics of the two cotton bales at different stages of processing, determined via AFIS.

Fiber Property	Bale #1			Bale #2		
	Bale	Chute	Carded	Bale	Chute	Carded
Nep count (/g)	330.00	445.00	38.00	247.00	364.00	6.00
Mean length – *n*-based (cm)	2.00	1.98	1.91	1.98	2.00	1.83
Short fiber content – *n*-based (%)	23.00	23.90	28.80	25.00	23.20	29.90
Mean length – *wt.*-based (cm)	2.44	2.41	2.41	2.41	2.41	2.29
Short fiber content— *wt.*-based (%)	8.30	9.00	10.80	9.00	8.30	11.90
Upper Quartile Length (cm)	2.90	2.90	2.97	2.92	2.92	2.82
Trash count (/g)	37.00	18.00	3.00	16.00	10.00	1.00
Dust count (/g)	244.00	95.00	66.00	69.00	33.00	10.00
Fineness (mtex)	169.40	165.40	153.80	177.80	175.00	174.20
Maturity ratio	0.88	0.86	0.88	0.88	0.88	0.85

Table 2 Mechanical properties of the hydro-entangled cotton non-woven fabrics made with varying water pressures (HP) and a constant pre-wetting pressure (LP) of 30 bars.

Water Pressure (HP) *(bar)*	Burst Strength *(bar)*	MD Tensile Strength *(N/50 mm)*	MD Elong. *(%)*	CD Tensile Strength *(N/50 mm)*	CD Elong. *(%)*	MD Tear Strength *(N)*	CD Tear Strength *(N)*
50	1.35	23.17	63.58	31.33	61.33	6.85	7.38
75	1.64	55.48	40.09	65.20	60.50	10.23	13.57
150	0.85	77.00	14.25	54.25	53.50	6.94	5.96
200	0.67	76.77	7.20	55.16	40.87	6.01	4.31

HP, high pressure; LP, low pressure; MD, machine direction; CD, cross direction.

machine direction, which probably can be attributed to the initial orientation of fibers in the cross-lapped/needle-punched web. The H-E process and especially its HP, however, changes the orientation of the fibers in the fabric. Microscopic examinations of the structures of the fabrics produced with different HP pressures reveal that as the (HP) pressure is increased, progressively more well-defined "strands" of highly entangled fibers are observed in the machine direction (Figure 3). The formation of these so called condensed strands of entangled fibers is partly attributed to the increase in the MD strength up to a certain optimum point or limit, after which a decrease in strength, possibly due to the fibrous strands' excessive stiffness and hence brittleness, occurs with an increase in the pressure. Obviously, while these "pseudo-strands" of highly entangled fibers contribute to an increase in the MD strength, the CD strength decreases, as seen at a HP of 150 bar. The breaking or failure elongations of the fabrics are typical of comparable non-woven substrates made with comparable staple fibers.

Initially, the tear strength in both directions reaches a maximum at 75 bar before steadily falling as the pressure is

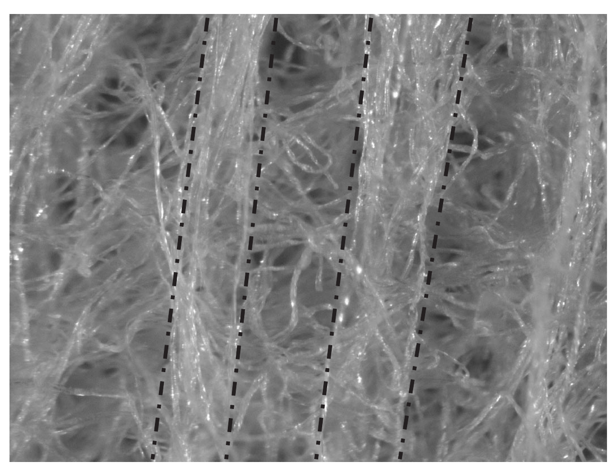

Figure 3 Well-defined "strands" (denoted by the dashed lines) of fibers as observed in the machine direction.

Table 3 Physical properties of the hydro-entangled cotton non-woven fabrics made with varying water pressures (HP) and a constant pre-wetting pressure (LP) of 30 bar.

Water Pressure (HP) *(bar)*	Weight *(g/m²)*	Thickness *(mm)*	Dimensional Changes *MD : CD* *(%)*	Drop Test *(s)*	MD Wicking 2 cm *(s)*	CD Wicking 2 cm *(s)*
50	48.9	0.645	Fragile	>100	>600	>600
75	54.1	0.570	−10.0 : +4.0	9.0	>600	>600
150	63.9	0.508	−11.0 : +2.5	<1.0	24.3	>600
200	50.5	0.470	−12.0 : +3.5	<1.0	11.7	>600

HP, high pressure; LP, low pressure; MD, machine direction; CD, cross direction.

increased to 200 bar. Again, the formation of the so-called pseudo-strands of progressively more entangled fibers due to the greater HP energy seems to be a logical attribute of this observed phenomenon of the decreasing tear strength with the increasing HP pressure. It seems that a progressively wider (non-fibrous) "empty void or channel" (which alternately is formed corresponding to each adjoining pronounced "fibrous strand" that is created by a progressively increasing HP) contributes to an easier tear along the channel. This same phenomenon may also explain the effect of HP on the fabric burst strength, which also decreases with the increasing HP and the resulting increased fabric porosity.

Table 3 shows the physical properties of the fabrics. As expected, the thickness of the fabrics decreases with the increasing HP. The dimensional changes in the MD and CD of the fabrics after an ordinary (process) wash are typical of a cotton non-woven fabric of equivalent construction. Since the fabric formation involved considerable MD tension during processing and drying, the fabrics on relaxation after the "process wash" shrank quite a bit in the machine direction, while slightly stretching in the CD, as seen. The effect of HP on the fabric's dimensional characteristics and hence stability appears to be insignificant. Incidentally, although the test data on the fabrics' dimensional characteristics after repeated launderings could not be presented here in this manuscript, it may be noted that the dimensional stability of the fabrics up to 10 normal household laundering cycles was good, consistent and better than expected, i.e. the total MD shrinkage during the 10 launderings (after the first "process wash") was less than 3%.

The drop test data show that the fabrics become increasingly absorbent, i.e. hydrophilic, as the HP is increased. One possible explanation for this trend is that at higher HP, more of the hydrophobic constituents (waxes) that are typically found on the primary wall of cotton fiber are removed by the high hydraulic energy of the H-E process. A previous preliminary study [16] on the analysis of effluent water of the process had shown the presence of some of the heavy hydrocarbons associated with the outer (hydrophobic) membrane of cotton fiber. Another and more testable explanation, based on the examinations of SEM pictures of the fabrics, is that at high HP pressures the cotton fibers become increasingly fibrillated and thus more absorbent, because the inner, secondary (hydrophilic) walls of the cotton fibers are more exposed.

At low HP pressures, the amount of wicking in both the machine and cross directions is comparable; however, at pressures above 150 bar, the wicking in the machine direction is significantly greater than that measured in the cross direction. This trend in the wicking data can again be attributed to the previously described formation of the well-entangled fibrous strands in the machine direction. Based on visual observations, the so-called "empty channels" accompanying the adjoining well-entangled "fibrous strands" are partly responsible for the observed wicking behavior in the machine direction of the fabrics. In addition, the HPs, as also stated previously, may reduce the amount of waxes on the surface and also initiate some damage to the fibers, ultimately increasing the wicking ability of the fabrics produced.

To further elucidate the effects of (HP) water pressure on the mechanical properties of the fabrics, a similar trial to that described above was conducted with one significant change in that the pre-wetting pressure (LP) was increased from 30 to 50 bar. The resulting mechanical and physical properties of the fabrics produced are listed in Tables 4 and 5, respectively. As seen, the data in Tables 4 and 5 exhibit trends very similar to those observed for the data at 30 bar listed in Tables 2 and 3. However, it is important to note that the absolute (quantitative) values of the measured mechanical and physical properties of the fabrics produced using a pre-wetting pressure of 50 bar are different from those of the fabrics produced by using a pre-wetting pressure of 30 bar. Comparing the data in Table 2 with that of Table 4, it is clear that cotton fabrics produced using a pre-wetting pressure of 50 bar are stronger in both tensile and tear strengths than those produced by using the lower pre-wetting pressure (LP) of 30 bar. Increasing the pre-wetting pressure by a factor of ~1.7, yields a 75% increase in the MD tensile strength at 50-bar HP. However, as the HP is increased, the referenced difference becomes less signifi-

Table 4 Mechanical properties of the hydro-entangled cotton non-woven fabrics made by varying HP pressures and a constant pre-wetting pressure of 50 bar.

Water Pressure (HP) *(bar)*	Burst Strength *(bar)*	MD Tensile Strength *(N/50mm)*	MD Elong. *(%)*	CD Tensile Strength *(N/50mm)*	CD Elong. *(%)*	MD Tear Strength *(N)*	CD Tear Strength *(N)*
50	1.72	40.35	60.13	49.65	54.33	9.21	10.41
75	1.71	59.97	39.87	69.28	49.74	9.96	13.34
100	1.6	73.02	30.54	65.83	48.87	9.65	9.96
150	1.06	86.27	13.87	77.74	49.67	7.56	7.12
200	0.48	82.35	6.80	59.44	44.87	7.65	6.14

HP, high pressure; LP, low pressure; MD, machine direction; CD, cross direction.

Table 5 Physical properties of the hydro-entangled cotton non-woven fabrics made by varying HP pressures and a constant pre-wetting pressure of 50 bar.

Water Pressure (HP) *(bar)*	Weight (g/m^2)	Thickness *(mm)*	Dimensional Changes *MD : CD* *(%)*	Drop Test *(s)*	MD Wicking 2cm *(s)*	CD Wicking 2cm *(s)*
50	53.0	0.516	–10.5 : +2.8	>100	>600	>600
75	53.4	0.490	–11.5 : +2.5	>100	>600	>600
100	54.7	0.488	–12.0 : +1.5	21.0	>600	>600
150	53.4	0.460	–12.8 : +2.5	<1.0	16.3	>600
200	52.1	0.470	–12.5 : +1.0	<1.0	8.7	35.0

HP, high pressure; LP, low pressure; MD, machine direction; CD, cross direction.

Table 6 Mechanical properties of cotton non-woven fabrics hydro-entangled at varying pressures with a constant pre-wetting pressure (LP) of 50 bar.

Water Pressure (HP) *(bar)*	Weight *(g/m^2)*	Thickness *(mm)*	MD Tensile Strength *(N/50mm)*	MD Elong. *(%)*	CD Tensile Strength *(N/50mm)*	CD Elong. *(%)*	MD Tear Strength *(N)*	CD Tear Strength *(N)*
75	47.9	0.498	37.88	47.93	40.06	68.53	7.43	7.92
100	49.4	0.500	64.54	34.93	56.88	58.40	6.76	9.03
125	48.6	0.478	65.83	21.74	55.32	53.73	6.72	7.74
150	46.5	0.472	68.30	17.53	55.06	49.80	5.74	6.94
175	46.7	0.465	66.24	9.60	48.60	43.13	5.47	5.92

HP, high pressure; LP, low pressure; MD, machine direction; CD, cross direction.

cant. At a maximum HP of 200 bar, the referenced MD gain is only 6.8%. Similar results are obtained when comparing the tensile strengths measured in the CD. This indicates that both the pre-wetting (LP) and the fiber entangling (HP) pressures affect the properties of the cotton non-wovens produced.

To examine the reproducibility of the research results presented above, cotton from Bale #2, which was processed in similar manner to cotton from Bale #1, was used to repeat the H-E process, using LP at 50 bar and HP ranging from 75 to 175 bar, keeping the other processing conditions practically the same as in processing the cotton from Bale #1. The fiber properties of the cotton from Bale #2 can be found in Table 1. Table 6 shows the properties of the hydro-entangled fabrics made with this cotton. The tensile and tear data in Table 6, although quantitatively somewhat different as expected, show trends almost similar to those observed from Table 4 of Bale #1.

Table 7 Mechanical properties of hydro-entangled cotton non-woven fabrics produced at constant pre-wetting (LP) pressure of 40 bar and fiber entanglement (HP) pressure of 150 bar and by varying the process speed.

Process Speed *(m/min)*	Weight *(g/m²)*	Thickness *(mm)*	Burst Strength *(bar)*	MD Tensile Strength *(N/50mm)*	MD Elong. *(%)*	CD Tensile Strength *(N/50mm)*	CD Elong. *(%)*	MD Tear Strength *(N)*	CD Tear Strength *(N)*
5	82.8	0.526	2.54	149.17	23.20	143.11	43.41	11.07	10.81
10	89.2	0.564	2.73	140.16	30.74	141.72	45.20	10.67	10.68
15	87.6	0.564	2.63	132.73	34.20	138.08	47.00	12.01	12.32
20	85.7	0.579	2.83	106.13	35.94	125.06	49.60	13.34	14.19
25	80.2	0.605	2.31	103.25	37.67	122.39	52.00	13.12	14.32

HP, high pressure; LP, low pressure; MD, machine direction; CD, cross direction.

Table 8 Physical properties of cotton non-woven fabrics hydro-entangled at constant pre-wetting of 40 bar and entanglement pressure of 150 bar using varying process speeds.

Process Speed *(m/s)*	Weight *(g/m²)*	Thickness *(mm)*	Dimensional Changes *MD : CD (%)*	Drop Test *(s)*	MD Wicking 2cm *(s)*	CD Wicking 2cm *(s)*
5	82.8	0.526	–10.3 : –0.3	5.0	>600	8.3
10	89.2	0.564	–9.8 : 0.0	23.0	>600	24.7
15	87.6	0.564	–9.5 : –0.3	63.0	>600	44.0
20	85.7	0.579	–10.0 : +1.0	>100	>600	>600
25	80.2	0.605	–10.5 : +3.0	>100	>600	>600

HP, high pressure; LP, low pressure; MD, machine direction; CD, cross direction.

To further examine the effects of H-E process parameters, the effect of process speed was investigated using a carded cotton web that had been cross-lapped eight times before being lightly pre-needled. In this study the pre-process and entanglement pressures were held constant at 40 and 150 bar, respectively, while the process speed was varied from 5 to 25 m/min. The mechanical properties of the fabrics thus produced are listed in Table 7.

As seen in Table 7, the MD and CD tear strengths increase as the process speed is increased; however, the strength reaches a plateau at around 20 m/min. Conversely, the tensile strength in both the MD and CD decreases as the speed is increased until the strength reaches a plateau at around 20 m/min. Since the feed material used in this trial to examine the effect of process speed has a greater number of laps, i.e. eight compared with five, the magnitudes of the strengths, as expected, are greater than the fabrics made with the 5-lap source material. A heavier, thicker material is clearly expected to be stronger than a lighter, thinner material. Initially the tensile strength in the machine direction is greater than that measured in the CD; however, at 10 m/min the tensile strength in the CD over takes that of the MD. It is also observed that speed and pressure are inversely related in context with the degree or impact of H-E (as evaluated by the physical properties of the fabric) attained (Table 8). Thus, decreasing the process or production speed apparently produces a more hydrophilic fabric, a trend similar to that observed with the increasing HP (and, hence, hydraulic energy).

To further investigate the overall increase in absorbency as either the pressure is increased or the speed is decreased, samples of the cotton non-woven fabrics produced using a pre-wetting pressure of 50 bar and entanglement pressure ranging from 50 to 200 bar were examined using a Phillips environmental SEM. A gold/palladium coating of approximately 15 nm was deposited onto the cotton fabrics via sputtering. The fabrics were examined up to a magnification to 3000×. Figure 4 shows the SEM images of the various fabrics at a magnification of 500×. An image of carded cotton at 500× was included in Figure 4 for the sake of comparison.

The SEM images in Figure 4 reveal that the HP water pressures greater than 75 bar begin to cause noticeable fiber fracture (fibrillation) on the fabric surface. Fibrillation of the cotton fibers becomes more pronounced and widespread as the HP approaches 200 bar, the maximum examined in this study. A similar trend is observed with decreasing speeds, where little to no damage is observed using a HP pressure of 150 bar at 25 m/min and significant fiber fibrillation occurs when the same HP pressure is com-

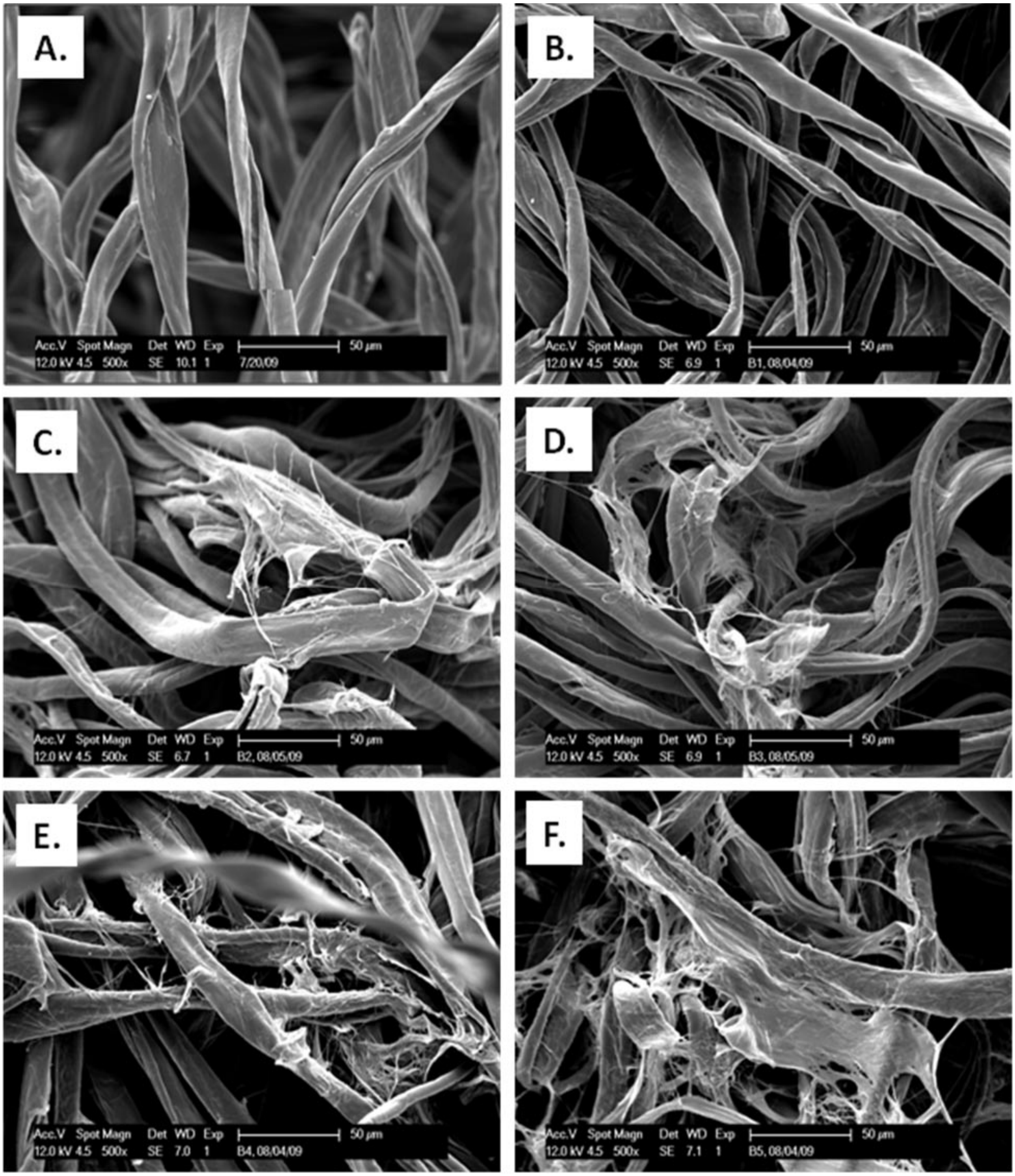

Figure 4 SEM images of the hydro-entangled, greige-cotton non-woven fabrics produced at a constant pre-wetting pressure of 50 bar and the entanglement (HP) pressures ranging from 50 to 200 bar: (A) only carded cotton web; (B) 50 bar; (C) 75 bar; (D) 100 bar; (E) 150 bar; and (F) 200 bar.

bined with a speed of 5 m/min. The images in Figure 4 support the drop test data in Tables 3, 5 and 8 and confirm that combining high HPs with slow process speeds results in the cotton fibers become increasingly fibrillated and thus more absorbent, because the inner, secondary (hydrophilic) walls of the cotton fibers are readily exposed. In addition, the SEM images in Figure 4 aid in our ongoing research into optimizing HE process conditions (LP, HP and speed) to yield an undamaged non-woven cotton fabric with optimal mechanical properties.

The pictures in Figure 4, along with the data in Tables 2–7 and some of high-powered optical microscopic views of the fabrics studied clearly show that the HP water pressure/energy involved in the H-E system plays a critical role not only in the degree or efficiency of fiber entanglements but also in the several other critical fabric properties and quality characteristics, such as absorbency, appearance, hand, permeability (voids, pore size, bulk, opaqueness, cover factor, etc.), and, hence, ultimate fabric quality and utility. Of course, the resulting effect of hydraulic energy on fabric properties also depends on many other factors, including the fiber material, the material assembly and the linear density, in addition to the H-E process parameters and hardware factors (such as the construction of the condensing and supporting belts, the profiles and configurations of jet-strips, the number of the HP jet heads available, and so on) [17–19]. Future work will be devoted to determining the effects of those major factors on the process and product performances of non-wovens made of mostly greige cotton content.

Summary and Conclusion

A preliminary study was conducted on a state-of-the-art commercial non-wovens machinery and equipment to determine efficiency of processing a regular, greige (scour/bleach-less) cotton for producing certain non-woven fabric substrates. The mechanical processing involved in the study went smoothly and presented no significant difficulties or problems. The cotton was cleaned of its foreign matter beyond our expectations. The fabrics produced exhibited normal properties, as expected. It appears that the absorbency of greige fabrics, which is critical for most cotton end-use applications, can be controlled by optimizing the processing metrics, especially the water pressures (i.e. hydraulic energy) of the H-E process. The preliminary indications are that, depending on the base material type and density and the various processing conditions, there are certain "threshold limits" of the water pressures when the greige cotton non-woven fabrics first become partly hydrophilic (from the original hydrophobic stage) and then at higher pressures, the fabrics become wickable and absorbent. Also, an ordinary washing, using warm water and a common detergent, makes certain fabrics almost totally absorbent (hydrophilic).

SEM examinations of certain hydro-entangled fabrics (made of certain specific constructions/densities and with water-jet pressures beyond certain threshold values) reveal that some fiber fracture or fibrillation can occur on the fabric surface, which could be favorable depending on the end-use application of the fabric substrates. In addition, the research has also shown that the fabric hand and other physical properties change considerably with the hydraulic energy used. Generally, a fabric becomes harsher and less opaque with the increasing water pressures. At any rate, there still are many, many technical issues that need to be precisely investigated and answered. Different web constructions and densities, different production speeds, and different water pressures and chemistries need to be investigated, in order to develop reliable and sustainable relationships among the various process variables. Therefore, this initial, preliminary work of exploring feasibility of producing non-wovens of greige cotton content will be followed by an aggressive pursuit of research with different qualities of cotton and cotton blends and with different processing parameters to develop cotton-containing non-woven fabrics for specific end-use products and applications. Research efforts will continue to optimize the various processing conditions throughout the cotton non-wovens production systems to produce commercially viable non-woven products, primarily using greige (bleach-less) cotton. However, based on the results of the preliminary study presented here, it appears almost certain that greige cotton indeed is a viable and promising candidate for incorporation into existing and new non-woven textile and related products for many end-use applications, such as disposable/reusable/recyclable/semi-durable and even durable wipes, uniforms, towels, sheeting, tablecloths, napkins, flushable articles, pajamas, and perhaps even sustainable "green" denims, all of which can be produced using cotton fiber and/or material of appropriate quality.

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