SOME ADVANCES IN NONWOVEN STRUCTURES FOR ABSORBENCY, COMFORT AND AESTHETICS

Jacek Dutkiewicz

Buckeye Technologies Inc., Memphis, TN, USA

Abstract

Modern disposable articles for personal and health care should offer excellent absorbency as well as comfort in use, need to be aesthetic and ensure discretion. There are numerous challenges facing the designers of nonwoven fabrics for absorption of body fluids, which result from various engineering contradictions. Combining all necessary functions, i.e. fluid acquisition, distribution and retention, in one uniform, simple composite made of fibers and superabsorbent polymer particles may be problematic. One can easily predict from theory that improving one parameter will result in a deterioration of another function. High-performance, multifunctional unitary structures require separation of functional components and their placement in a nonwoven web in a predetermined, oriented fashion. Some examples of such structures are proposed here and the experimental test results are discussed to demonstrate the advantages of the studied materials. The aesthetics of the finished article as well as the comfort of their use depend mainly on the bulk and mechanical properties of the absorbent core, such as integrity, softness and pliability. The paper provides some examples of engineered nonwoven webs having these desired attributes.

1. INTRODUCTION

Increasing global demand for disposable personal and health-care articles has resulted in stiff competition for unique and improved absorbent products. Today, personal hygiene goods alone constitute substantial, multibillion-dollar business. This situation is due to growing basic care needs of hundreds of millions of infants, children, millions of women using feminine hygiene articles, and adult people suffering from incontinence. Only in Europe alone, there are more than 10 million elderly people in need of medical care absorbent devices. By and large, the demand for personal care products has become very high especially in industrialized countries and is continuously expanding in developing nations. In well-established markets of higher economical status the producers are faced with a challenge of meeting ever-rising consumer expectations for step-out improvements in product performance, quality and aesthetics. This paper will discuss some advances in selected areas of absorbent materials, structures and systems.

2. CHALLENGES RESULTING FROM STRUCTURE-ABSORBENCY RELATIONSHIPS

Body fluids are aqueous solutions, colloids or dispersion, whose properties are controlled greatly by water. Water is unique when compared to other liquids primarily due to its dipolar character. This feature leads to high cohesiveness and solvating power of the molecules. As a result water has higher melting and boiling point, is more viscous and has higher surface tension than other liquids of a similar chemical structure, such as simple alcohols and ethers. The mechanism of fluid flow in fiber networks depends on the physical properties of the liquid, mainly its viscosity and surface tension as well as on the structural characteristics of the solid absorbent material. For instance, certain components of urine have surface-active properties, so high surface tension of water is reduced in this case from about 70 to about 55 dynes/cm. Cells and proteins constituting the composition of blood or menses increase the viscosity of this suspension from 1 to 5-10 centipoises.

From the absorbency standpoint a given liquid can be characterized by the *fluid rate constant*, Ψ, which is the ratio of the liquid's surface tension, γ, and viscosity, η. The units of Ψ are the same as those of linear velocity, *e.g.* m/s. Consequently, liquids having higher surface tension and lower viscosity will be considered "faster" whereas more viscous fluids with lower surface tension will be thought of as "slower". Therefore, water is a fast liquid whereas blood is a slow liquid, which is in agreement with our common sense. Table 1 contains some numerical values of the fluid rate constant, Ψ, for some typical liquids used in acquisition rate measurements.

Table 1. Fluid rate constant Ψ

Liquid	Surface tension, γ, dyne/cm	Viscosity, η, centipoises	Ψ, m/s
Water, saline (0.9% NaCl)	75	1	75
Blood simulant	65	9	7.2
Urine	~55	1	~55

The *fluid rate constant* was coined by Dutkiewicz [1] and can be used in a fluid acquisition model quantifying the rate of liquid intake within a uniform fiber network:

$$R_{An}' = (1.57\,\Psi \varepsilon^2 a \cos\Theta_A) / (1 - \varepsilon)\,\rho_W \tag{1}$$

where R_{An} is the acquisition rate normalized per unit basis weight of the absorbent web, ε is the porosity of the fabric, a is the efficient radius of the fiber, Θ_A is the advancing contact angle and ρ_W denotes the apparent web density. Equation (1), derived with the aid of the known Lucas-Washburn and Kozeny-Carmen theories, incorporates void volume of the absorbent structure (equal to ε/ρ_W). The void volume is need by the intake material to store the acquired liquid until it is transferred to other components of the system. The relatively simple equation (1) is useful for situations where rather small amount of fluid is secreted from the body. It gives a guideline for the designers of absorbent fabrics about the key structural parameters that should be used to control the acquisition function of a uniform nonwoven structure. The model becomes more complex for higher fluid discharges [1].

It is convenient to divide the mechanism of fluid management by a porous medium into three basic categories: acquisition, distribution and retention. First, the discharged liquid should be quickly acquired before it is transferred to other parts of the absorbent core. Sufficient void volume is required in the intake zone, as reflected by equation (1), to avoid leakage or runoff. In order to maintain sufficient capacity in the acquisition area for subsequent discharges, a properly designed system is expected to move the liquid away from the acquisition region to more remote parts of the core and distribute it within its structure. In the case of higher capacity systems, which have to handle large amounts of liquid, it has been a challenge to design a web capable of moving the fluid high enough with sufficient flux. Figure 1 illustrates a progress of filling up a U-shape absorbent core, in which the liquid needs to be moved up to make use of the absorbent mass at the ends of the web. This is in fact difficult to achieve so a traditional solution is to locate most of the absorbent material in one place, *i.e.* in the discharge area. However such an arrangement creates much discomfort for the user, not to mention the lack of discretion.

The rate at which the fluid moves upward at a given height, H, can be expressed by the well-known Lucas-Washburn relationship for capillary flow:

$$dH/dt = (\gamma\ r \cos\ \Theta_A\, 4\,\eta\ H) - (r^2 \rho_L\, g / 8\,\eta) \tag{2}$$

where H is the height of the liquid column, t is the time of wicking, r denotes the efficient web pore radius and ρ_L is liquid density. As seen from equation (2) the process of upward fluid flow is driven by capillary tension but is opposed by gravity and by viscous drag, which also increases as the liquid column becomes higher. Figure 2 illustrates the theoretical impact of the web pore size on wicking rate and height. By looking at these graphs one can appreciate the challenge facing the engineers whose task is to develop an efficient distribution material. On one hand, thinner capillaries produce more tension, which translates into higher achievable wicking height. On the other hand small r values mean poor permeability and consequently low wicking rate and flux. It is also apparent that good acquisition material will not perform well as a wicking web and vice versa. The structural requirements for these two functions create typical engineering contradiction.

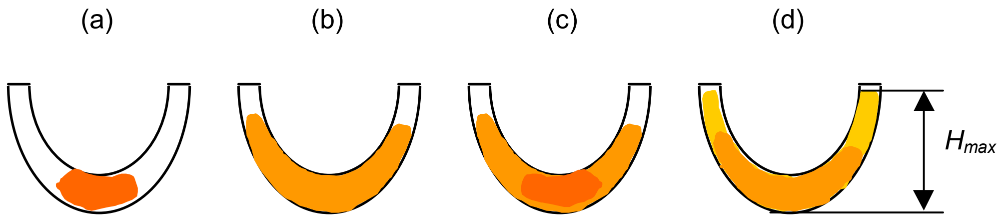

Figure 1. Progressive distribution of acquired liquid in absorbent system due to wicking against gravity (darkness of colored areas represent concentration of liquid):
a) shortly after first insult; b) partially distributed fluid;
c) shortly after second insult; d) fluid distribution after use

Finally, the absorbent composite ought to immobilize and retain the aqueous matter lest the moisture should flow back to the surface. When the quantity of liquid to be contained is high (100-500 mL) it is common to include superabsorbent polymer (SAP) powder within the fiber matrix. In a practical sense, to qualify as a superabsorbent, a dry polymer should imbibe 20 to 50 times its own weight of aqueous liquid. This means considerably more than a capacity of a matrix of cellulose fluff, *i.e.* 5-10 g/g depending on the type of pulp and extent of interfiber bonding. Many natural and synthetic polymers, both polyionic and those with no electrical charge can meet the above absorbency and integrity criteria [2]. However, only superabsorbent materials based on partially neutralized, randomly crosslinked polyacrylic acid gained so far commercial significance.

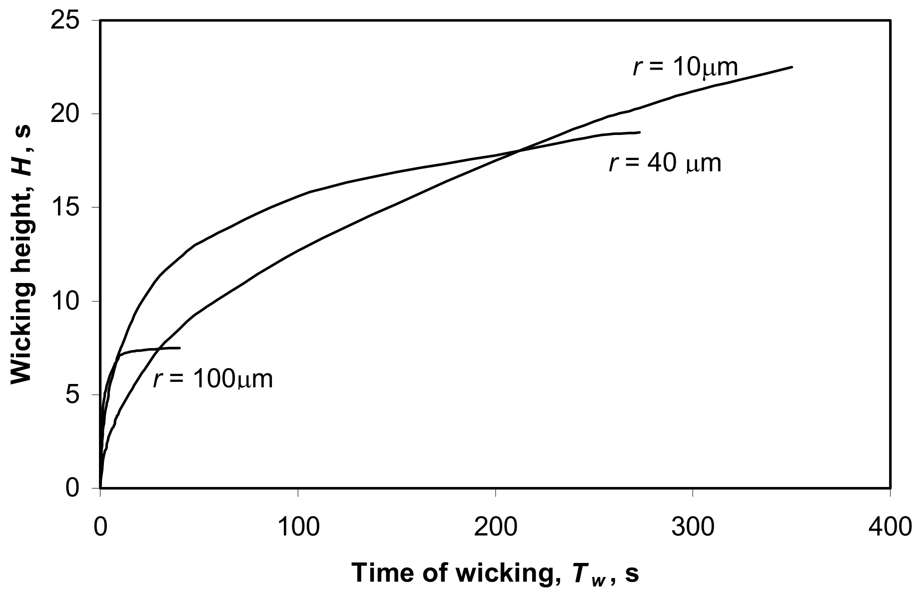

Figure 2. Vertical wicking of liquid in porous cellulose web, based on equation (2). Liquid parameters (as for 0.9% saline): γ = 75 dynes/cm; η = 1 centipoise; Ψ = 75 m/s; advancing contact angle Θ_A = 60°

In an absorbent system SAP particles will compete with the wicking component, which is commonly a porous fibrous web, for any available liquid. This means that ensuring simultaneously good retention and distribution throughout the absorbent core would be again quite a challenge.

Last but not least, the consumer would like to use a personal care absorbent product, which would be not only efficient from the absorbency performance standpoint but also comfortable and invisible to others.

To achieve high comfort, aesthetics and discretion, the absorbent core needs to be thin, soft and pliable. Traditional materials based on a mixture of fluff and SAP powder are soft but rather bulky, uncomfortable and lack any integrity. Bonded nonwoven products offer good integrity but are often relatively stiff because of excessive interfiber bonding. Thickness can be reduced by web densification, however, thinness means less void volume and porosity, hence poorer absorbency, and sometimes also undesirable, board-like appearance.

It seems that high level of performance can be achieved by assembling various structural elements (fibers, superabsorbent polymer particles, binders) in an oriented fashion to separate individual functions and gain better control over the movement of liquid and its placement in specified locations within the absorbent core. This approach has been successfully implemented in various lower capacity absorbent systems such as feminine sanitary napkins. However, more demanding products such as adult incontinence articles and infant diaper cores require even more complex engineering work to meet both technical requirements and cost constraints. Therefore, the latter, modern nonwoven webs are in the early stages of commercial implementation.

3. ENGINEERING OF ABSORBENT NONWOVEN STRUCTURES

Probably the oldest material for disposable absorbent products is cotton cellulose, which has been utilized since the time of Egyptian civilization. Wood fibers in the form of fluff and then paper tissue were introduced at the end of the nineteenth century. The first disposable absorbent article of commercial importance was the sanitary napkin introduced after the First World War. Since then disposable products underwent many evolutionary and sometimes revolutionary changes. Today, manufacturers of personal and health care articles can take advantage of natural and synthetic fibers as well as functional particles such as SAP. These components can now be used in diverse forming technologies to produce bonded nonwoven structures. Combining multiple absorbent functions in one unitary structure has been a desire of the scientists and engineers for decades. Theoretical restrictions summarized briefly in the previous section along with certain process limitations still create further development opportunities for basic research and for material engineering.

3.1. Multifunctional Unitary Structure

Sufficient void volume in an absorbent network is essential for efficient fluid acquisition. Combining fiber matrix with SAP particles results in a transient increase of void volume at lower saturation levels (Figure 3). The mechanism of this phenomenon has been quantified by the author [1]. According to this model, a change in the void volume in the absorbent structure, ΔV_V, is a function of the degree of material saturation, s:

$$\Delta V_V = \{[1.24\ (\alpha_{SAP}/\rho_{SAP})^{1/3}]\ /\ (\rho_{Wo})^{2/3}[(s/\alpha_{SAP} + 1)^{1/3} - 1]\} - s/\rho_{SAP} \qquad (3)$$

where α_{SAP} denotes the mass fraction of SAP particles in the structure, ρ_{SAP} is the density of the superabsorbent material and ρ_{Wo} is the initial density of the web.

Theoretical changes in the void volume based on the above equation are displayed in Figure 4. The graphs show that the amount of available interstitial space in the absorbent structure reaches its maximum at a certain saturation of the material and then declines due to continued swelling of the SAP particles, which occupy more and more space around them. For example in the case of a structure characterized with α_{SAP} = 0.2, the maximum ΔV_V amounts to 6 cm^3/g at a degree of saturation between 5 and 10 mL/g. The shapes of the curves in Figure 5 suggest also that the generated void volume diminishes with increased content of SAP particles. As the saturation progresses, ΔV_V may eventually drop to zero or even become negative. The latter situation will result in a decrease in the permeability and so-called “blocking effect”, observed sometimes in SAP-containing structures.

The changes in the void volume predicted from the simple, theoretical model shown above can be confirmed by experimental measurements. For instance, a study conducted by Sawyer *et al*. [3] may be used as an example. These authors fabricated a number of bonded webs composed of softwood cellulose fluff, SAP and small amount of binder fibers. According to their data, absorbent structures containing 20% SAP (α_{SAP} = 0.2) had an initial void volume of 6 cm^3/g which was doubled at an optimum degree of saturation between 5 and 8 g/g. As seen in Figure 4, this experimental result is very consistent with the one obtained from our model. The structures produced by Sawyer *et al.* also exhibited further decline in ΔV_V although much more rapid than that illustrated with the theoretical curves. Such discrepancy at higher saturation may be explained by possible migration of more swollen SAP granules within a composite matrix as well as with intrinsic polymer properties such as particle size and shape distributions, gel modulus *etc.*

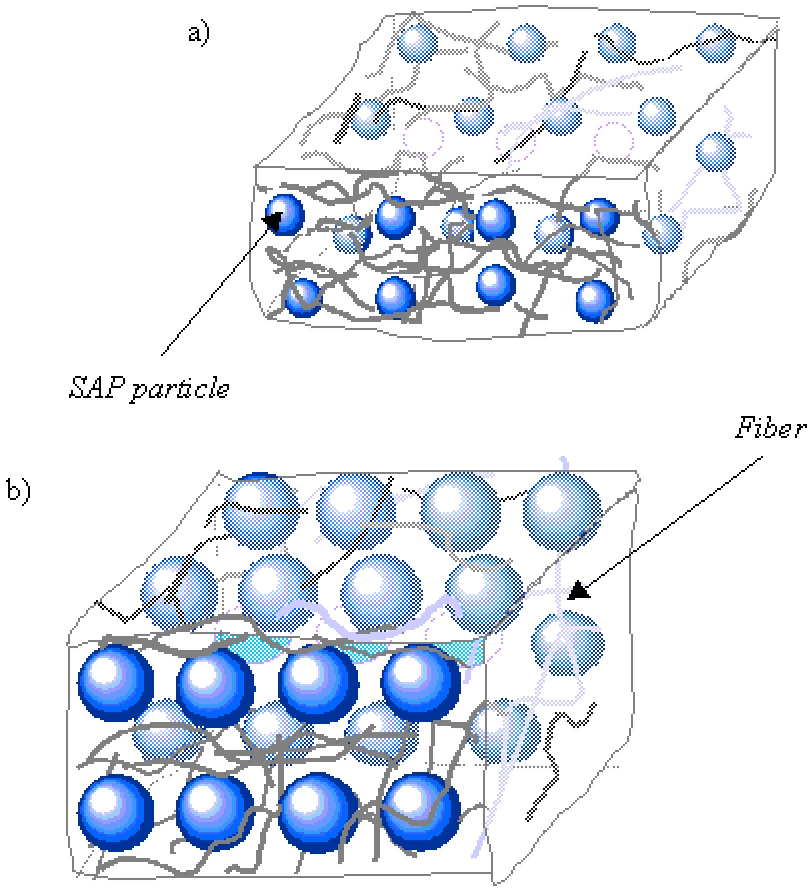

Figure 3. Ideal composite with uniformly arranged SAP particles:
a) in dry state; b) with swelled SAP particles

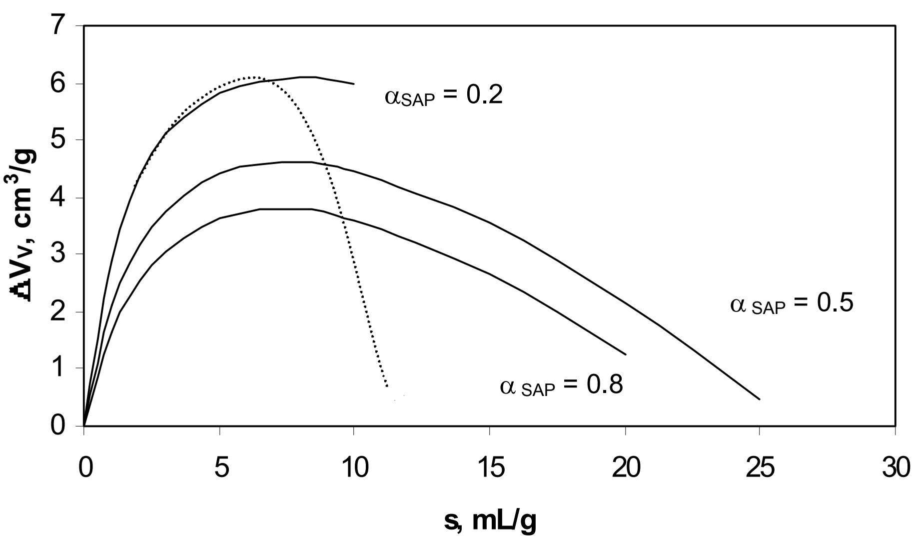

Figure 4. Changes in void volume in fiber/SAP composites in function of web saturation.
Dotted curve based on data by Sawyer *et al.* [3]

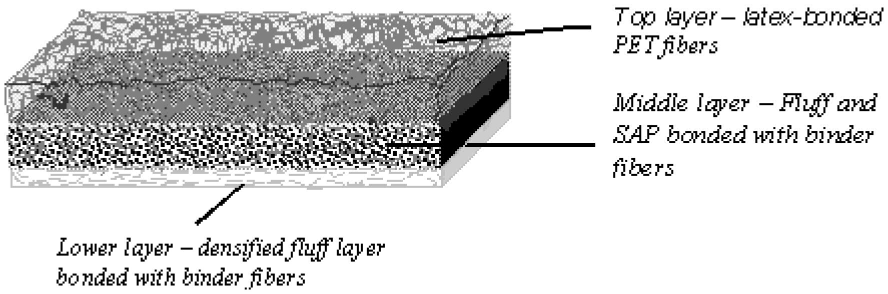

Figure 5. Schematic view of multilayer unitary ASP structure with z-directional density gradient for controlled fluid flow [5]

Based on the above considerations we can say that the fluid intake function of a simple fluff/SAP structure deteriorates gradually due to the swelling of the hydrogel. Are there any remedies to that? It seems that there are some solutions to this problem, which will be discussed here. For example, it was found by Erspamer *et al*. [4] and also by the author *et al*. [5] that *in situ* integration of a resilient, synthetic fibrous layer with a liquid storage composite into a unitary, bonded composite led to improved acquisition performance of the web without compromising its retention function. Figure 5 provides an example of such a unitary, acquisition/storage material.

All layers are integrated and bonded with a polymer resin or with bicomponent binder fibers. The top stratum, formed with synthetic fibers, has lower density and higher contact angle than the layers below. Its role is to acquire the liquid, transfer it to the stratum below it and maintain the dryness of the surface of the web. The middle layer serves for storing part of the liquid and for moving the rest of it away from the upper to the bottom stratum. The density of the latter is higher than that of the two other layers to ensure sufficient capillary tension for effective fluid distribution. In the invention disclosed by the author *et al*. [5] such a web contained SAP particles only in the middle stratum and was used an acquisition/storage ply (ASP) in a dual-core system containing also a retention or distribution/storage component as in Figure 6.

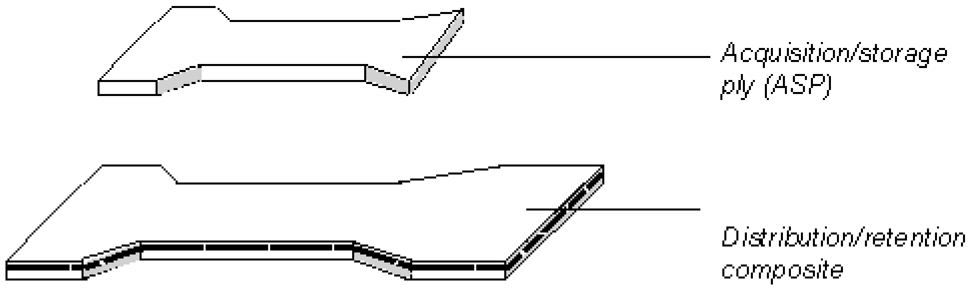

Figure 6. Exploded, perspective view of the components of an absorbent system comprising ASP structure as described in reference [5]

This system is particularly useful for high-capacity absorbent products, which are supposed to manage fast (high Ψ constant) liquids. Its efficacy was evaluated by introducing a performance parameter named *fluid acquisition and storage efficiency*, FASE. This parameter was defined by the following formula:

$$\text{FASE} = 100\, R_3\, C_{SAP} \tag{4}$$

where R_3 is the acquisition rate at the third liquid insult and C_{SAP} denotes the weight fraction of SAP component in the absorbent structure. A simple apparatus used to measure the acquisition rate is depicted in Figure 7.

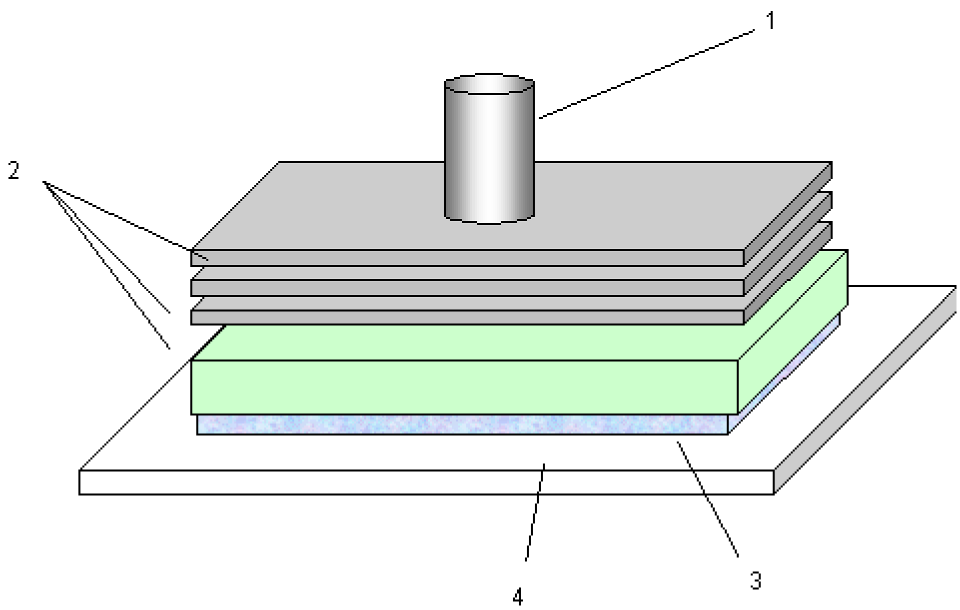

Figure 7. Schematic of test apparatus for acquisition, rewet and wicking distance tests.

1 – Tube for introducing test liquid;
2 – load plates used to control the pressure on the sample;
3 – foam applied to distribute the pressure uniformly on the sample;
4 – tested sample of the absorbent structure

It is generally a challenge to achieve a high FASE number with higher SAP concentrations for the reasons outlined before, *i.e.* an increase in C_{SAP} usually leads to shrinkage in void volume at higher saturation and a lower porosity of the absorbent fiber matrix. FASE will be also low for structures performing well as intake materials but containing small amount of retention component. The performance of the dual-core system of reference [5] was characterized by the rate of fluid acquisition measured under load of 2.8 kPa. Three insults of 0.9% saline, 75 mL each, were applied in this test. The results were compared to the data obtained by analyzing the intake properties of various traditional products available on the market. The data in Table 2 show that it was possible to achieve relatively high acquisition/storage efficiency with the experimental dual-core system. The corresponding FASE number was more than twice as high as that obtained for the conventional fluff/SAP composite.

Based on the description of the construction of the layered ASP material shown in Figure 5, one can imagine that there is little barrier or interface between the different layers in the stratified web. Such a structure is formed in one process using for instance airlaid technology (see Figure 8), in which the strata are dry-laid from a number of forming heads aligned in the machine direction [6].

Table 2. Absorbency performance of dual-core system versus traditional fluff/SAP composite [5]

Absorbent system	Total absorbent weight, g	SAP content, %	1st intake rate, mL/s	2nd intake rate, mL/s	3rd intake rate, mL/s	FASE, 10^{-2}mL/s
Experimental dual core ASP (0.02m^2, 400 g/m^2) DSP (0.04m^2, 330 g/m^2)	21.3	43.1	5.56	2.71	1.83	78.9
Fluff/SAP (0.036m^2, 649 g/m^2)	23.4	43.4	2.01	1.19	0.83	36.0

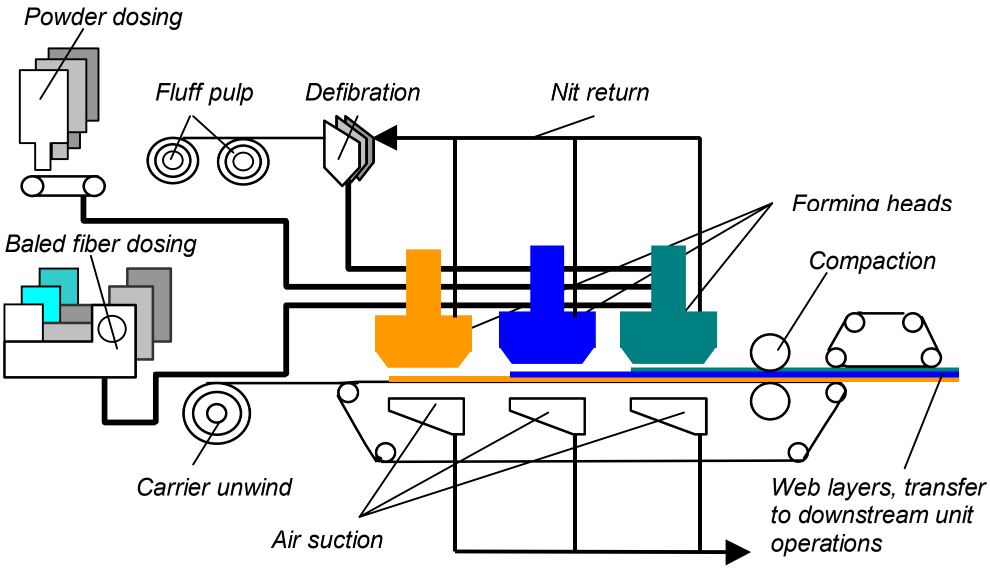

Figure 8. Schematic of the web-forming stage of the airlaid process

The intimacy of the contact between various layers of an absorbent structure or system has been recognized by the author *et al*. [7] as a key factor influencing the transfer of the liquid between the components of the nonwoven material. The developed model quantifies this structural feature as the *contact intimacy ratio*, CIR and is defined by equation (5):

$$CIR = \{[(\mu_3 - \sigma_3) - (\mu_1 + \sigma_1)] + [(\mu_2 - \sigma_2) - (\mu_3 + \sigma_3)]\} / [(\mu_1 - \sigma_1) - (\mu_1 + \sigma_1)] \quad (5)$$

where the significance of μ_1, μ_2, μ_3 and of σ_1, σ_3, σ_2 is illustrated graphically in Figure 9. In the structures disclosed by Baer *et al*. [4] and by the author *et al*. [5] the CIR is close to "zero" for each pair of adjacent strata. This is one of the important advantages of the unitary structures, which enables uninterrupted liquid flow from one layer to another.

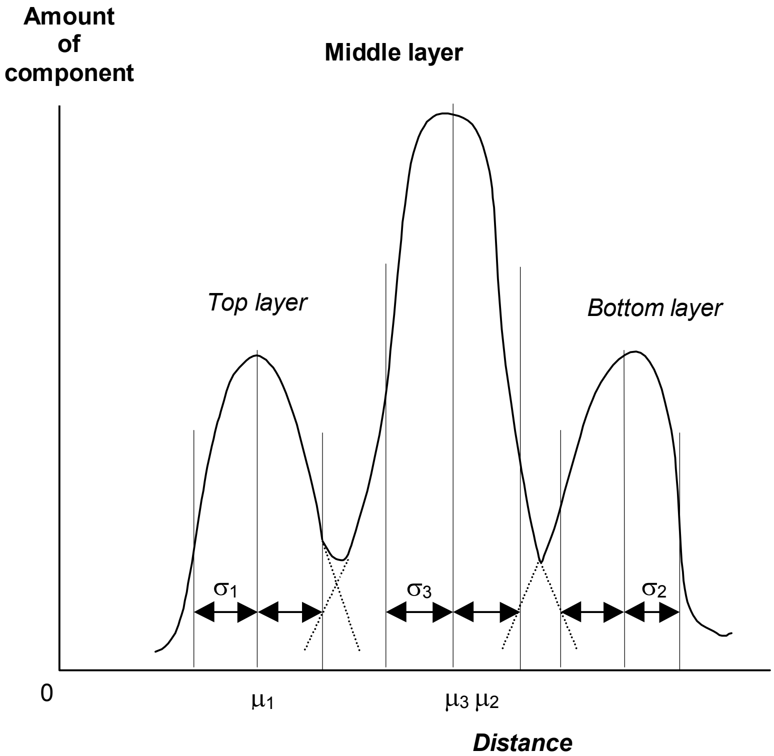

Figure 9. An example of contact intimacy in a three-layer structure [7]

The work conducted by Erspamer, Dutkiewicz *et al*. [8] revealed that high, combined fluid intake and retention performance could be achieved with engineered ASP materials characterized by a specially designed y-directional profile (y being a direction across the width of the absorbent core).

Figure 10 shows a schematic cross-sectional view of a bonded fibrous web with SAP particles, similar to the structures disclosed by the inventors. The top layer of the fabric is composed of synthetic fibers to facilitate fluid intake and maintain dryness. The middle stratum is divided into three zones: the two on either side having higher basis weight, density and SAP content than the central one. As a result of thus created capillary tension gradient in the y direction the liquid is moved to the sides of the sheet and locked in the retention component whereas the central zone can maintain lower degree of saturation and, consequently, higher porosity over an extended period of time. Some examples of such structures are specified in Table 3.

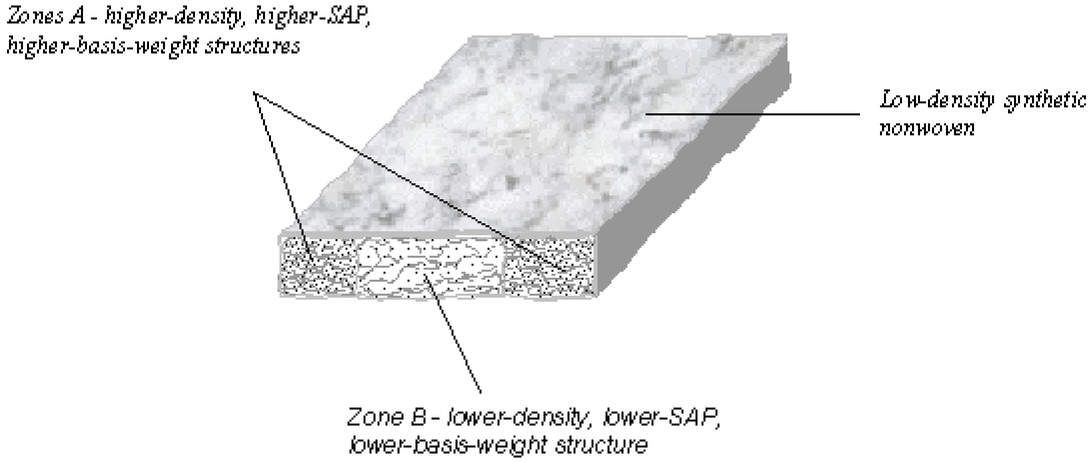

Figure 10. Schematic view of unitary ASP structure with y-directional gradient in density,basis weight and SAP content [8]

The data in Table 4 illustrate the advantage of the described design in terms of fluid acquisition and storage over a number of conventional, commercial absorbent cores (Table 5). The experimental systems were of a dual-core type and consisted of an ASP material (Table 4) having a general y-directional profile as shown in Figure 10 and a base core similar to that used in the previous work [5], mentioned above.

Table 3. Examples of unitary ASP structures with y-directional profile [8]

ASP example	Zone A				Zone B			
	Basis weight, g/m^2	Density, g/cm^3	SAP content, %	Zone width, cm	Basis weight, g/m^2	Density, g/cm^3	SAP content, %	Zone width, cm
“O”	551	0.305	60	2.5	273	0.203	50	5.1
“P”	562	0.214	60	2.5	282	0.136	50	5.1

ASP “0” – compressible southern softwood kraft (SSK) pulp in Zone A; regular SSK pulp in Zone B
ASP “P” – modified, compressible SSK pulp in Zone A; modified, cross-linked SSK pulp in Zone B

As can be seen from the data in Table 4 and 5, there is a dramatic difference between the FASE values of the engineered structures of reference [8] and the traditional absorbent composites based on heavy-basis-weight homogeneous blends of cellulosic fibers and SAP particles.

Table 4. Absorbency performance of some dual-core systems with y-profiled ASP [8]; ASP surface area 0.02m^2; DSP surface area 0.046m^2, 330 g/m^2

ASP in dual-core system	Overall system basis weight, g/m^2	SAP content based on whole system, %	Total absorbent capacity, g	3rd acquisition rate, mL/s	FASE, 10^{-2}mL/s
"O"	536	54.2	390	1.94	105.1
"P"	541	54.2	408	3.74	202.2

Table 5. Absorbency performance of some commercial products comprising traditional, unbonded SAP/fluff composite cores [8]

Infant diaper commercial product	Overall core basis weight, g/m^2	Overall SAP content, %	Total absorbent capacity, g	3rd acquisition rate, mL/s	FASE, 10^{-2}mL/s
1	710	40.1	443	0.55	22.1
3	658	36.8	321	1.24	45.6
6	820	42.6	537	0.33	14.1
7	750	14.7	422	0.21	3.1

3.2. High-performance, Pliable and Thin Nonwoven Structures

Pliability and thinness are the attributes having direct impact on the comfort in use, aesthetics and discretion. Pliability has various terms such as flexibility, bendability, suppleness or limpness. It can also be understood as an opposite feature to "stiffness" or "rigidity". Combining sufficient web pliability and integrity at the same time is usually a challenge since either of these attributes depends in different ways on the technique the web is bonded. Usually, the more strength a given structure gets by addition of more interfiber bonds the stiffer it becomes. In reality, mechanical properties of a fiber network are associated with its composition, frequency and kinds of bonds between fibers, possible, limited fiber flow, as well as other structural elements such as SAP particles, web construction and its uniformity.

Based on the relationship between the bending force and material thickness it would be obvious that increasing the basis weight of a uniform web without changing its composition or density will make it less pliable. However, compressing such a web will make it thinner, which could potentially reduce its stiffness according to the classic theory. On the other hand, permanent densification of a bonded web requires adding new bonds to stabilize the new, thinner structure. This in turn would yield a different, stronger material with a higher flexural modulus.

The pliability parameter was defined by Dutkiewicz *et al*. [5] as an inverse of Gurley stiffness and expressed in N^{-1}:

$$\text{Pliability } [N^{-1}] = 10^6/9.81 \text{ (Gurley Stiffness [mG])}. \qquad (6)$$

The pliability of conventional, unbonded fluff/SAP composites taken from commercial products was in a range of roughly 50 to 200 N^{-1} compared to 235 – 270 N^{-1}, characteristic of the wet-stable, bonded webs whose examples have been discussed above (Table 2-4). Therefore, the advantage of such bonded materials containing high amount of SAP particles is not only high absorbent capacity, and good integrity but also desired pliability, softness and small caliper relative to traditional composites. These attributes translate into much needed fit, comfort and discretion.

Continuous web forming processes rely on moving elements upon which the fibers and other components (*e.g.* binders, functional particles) are deposited and carried with some tension along the machine direction (MD). This movement and tension results in certain orientation of the structure and an anisotropic character of the produced material. As a result, mechanical properties of nonwoven webs may differ for instance in strength, elongation and stiffness depending on the direction of the applied measurement. These differences have to be taken into account when designing absorbent structures for personal care applications. In some cases the orientation is very distinct and is a consequence of the predetermined placement of structural elements within a web. A good example of such a situation is illustrated in Figure 11.

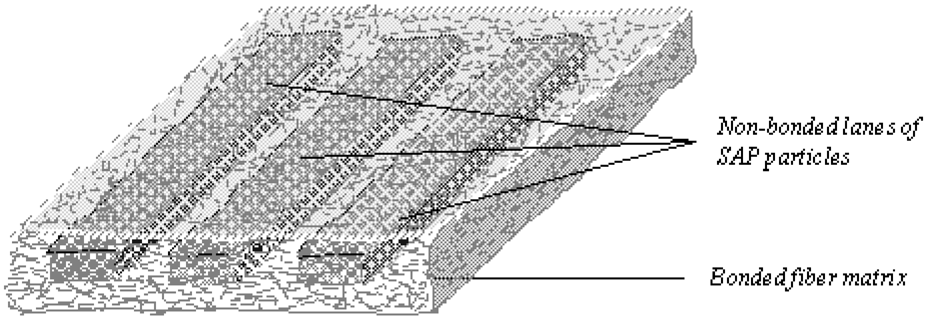

Figure 11. Schematic view of unitary structure with less bonded lanes of particles enclosed within well bonded fiber network [5]

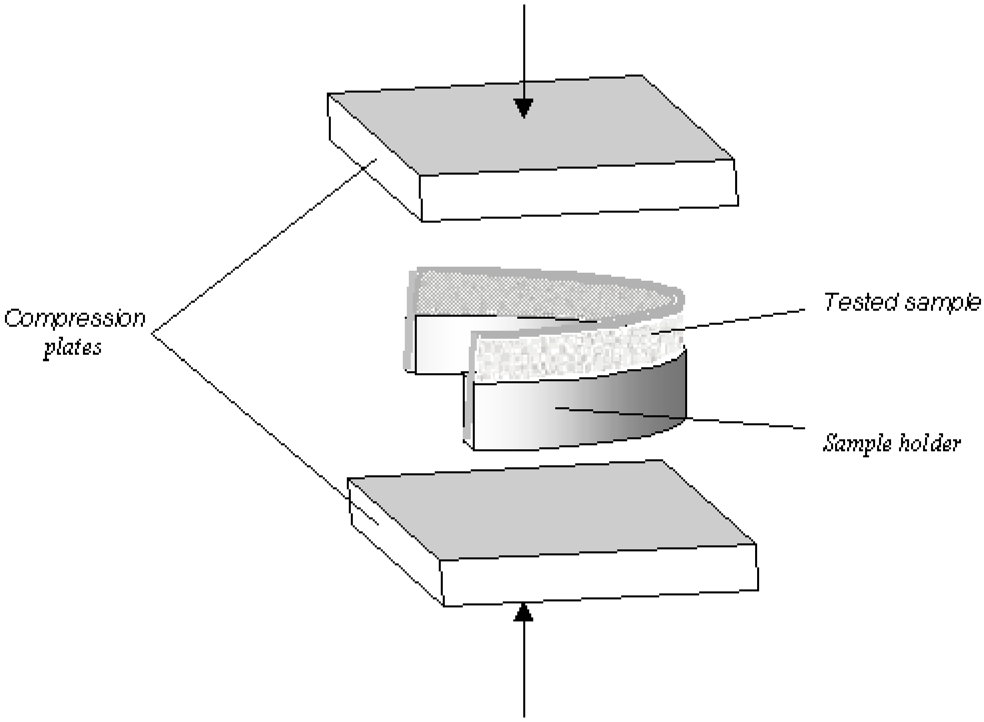

Figure 12. Measurement of CD softness according to reference [5]

It is a good practice to evaluate the stiffness of the material across its width (in the cross direction, CD) especially in those cases where the finished product is exposed to external side stresses. Such mechanical loads occur for example between the wearer's legs, in the crotch area. Excessive stiffness may create then both discomfort in use and may have an adverse effect on the functional performance of the hygienic article. Dutkiewicz *et al*. [5] offered a method of measuring the CD softness of absorbent sheets by placing a strip of material between two plates and applying force from both sides (Figure 12). A semi-circular clamp served to hold the sheet, whose shape then mimicked the anatomy of the human body. The softness was defined to be an inverse of the energy needed to compress the web to half of the sample's width, the latter being constant for all measurements. This energy, E_{dmax}, (expressed in J) was calculated at the maximum deflection according to the following formula:

$$E_{d\,max} = \int_{d\,min}^{d\,max} F\, dd \qquad (7)$$

where F is force at a given deflection d, and d_{min} and d_{max} are the deflections at the start of the test and at the end of the measurement, respectively.

According to the data reported in reference [5] the CD softness of some unbonded, traditional fluff/SAP composites, enclosed within their finished product shells ranged between 7.4 J^{-1} and 12.9 J^{-1}. Sheets of bonded absorbent cores developed by the authors [5] exhibited the CD softness of 13.1 to 37.5 J^{-1}. Higher softness of these experimental composites was achieved due to lower thickness, lower overall basis weight, and optimum amount of bonds and their appropriate distribution within the fiber matrix.

4. CONCLUDING REMARKS

During the times of the economical bubble of the late nineties of the past century the consumers' demand for better disposable personal care products was vigorously growing and the users were sometimes even ready to accept a reasonable price upcharge in return for significant performance improvements. When the bubble burst the new reality shifted the focus of the market on the cost as the primary concern. Consumers' needs and expectations usually dictate the trends in product evolution, which is then based on the results of research and development. The fact that the market may tolerate possible price increases with much greater caution does not mean that product performance is of no issue and the worries of the manufacturers are reduced to sorting out cheapest raw materials or cutting the production costs. Stiff competition and still very lucrative, global business of personal and medical care disposables creates fertile grounds for even more intensive efforts to find new materials and design products which will be both more cost-effective and better performing. Economy-driven needs may reduce the size of the box of scientific and engineering tools available for developing new technological solutions. However, such a situation often requires even more creativity and determination to achieve the desired result.

Looking back at the evolution of absorbent materials there have been a few clear breakthroughs in the past such as introduction of some nonwoven technologies or application of superabsorbent polymers. From the technical point of view, these achievements can be measured for example by step-out improvements in absorbency and fluid management. However, the true significance of a given invention will depend on the outcome of a concerted effort of a team of scientists, engineers, marketers and, last but not least, on visionary and managerial skills of industrial business leaders. Even though we may argue today that some new research and engineering achievements presented in this paper have potential to become future "breakthroughs" the final verdict will always rely on the scope of consumers' acceptance and satisfaction. One of the key technology platforms of future generations of bonded absorbent porous networks seems to be the web-forming process based on air laying of fibers along with other necessary functional components. Some advantages of this technology have been shown in this paper. One of the big challenges of this industry is the need to reduce the cost of highly engineered webs by improving their economics in terms of structural components (binders, SAP particles, functional synthetic fibers, cellulose fluff) and of the forming process.

Bibliography

1. *J.Dutkiewicz: Nonwoven Structures for Absorption of Body Fluids, monograph, publication pending, 2002.*
2. *J.Dutkiewicz: Advances in Polymer Materials for Medicine and Hygiene, Polish Academy of Science, Łódź, 2000.*

3. *L.Sawyer, A.Burnes, C.Hetzler: PCT Pat. Appl. WO 99/32165 (1998).*
4. *S.Baer, S.Li, J.Erspamer, J.Gross: PCT Pat. Appl. WO 00/74620 A1 (2000).*
5. *J.Dutkiewicz, J.Erspamer, B.Boehmer, S.Wahal, R.Hood: WO 00/41882 (2000).*
6. *B.Attwood, G.Moore: An Introduction to the Theory and Practice of Multiply Forming, Pira Technology Series, Edgerton Publishing Services, Huddersfield, UK, 1995, p.108-114.*
7. *J.Dutkiewicz, K.Goerg-Wood, D.Guay, M.Kalmon, B.Kressner, Y.Li, J.Qin, K.Szymonski, R.Tanzer, P.Wallajapet: US Pat. 6,329,565 B1 (2001).*
8. *J.Erspamer, J.Dutkiewicz, B.Boehmer, S.Wahal, R.Hood, M.Kalmon: PCT WO 01/35886 A1 (2001).*