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PAPERS

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INTERNATIONAL NONWOVENS Journal

GUEST EDITORIAL

How To Get Management To Increase Your R&D Budget

By Dennis R. Tavernetti President, BBA Nonwovens North America Hygiene, and INDA Vice Chairman/Finance

The successful inventor is one who invents something new and something that has value to others, because it creates more value than it costs. Remember that just inventing something that is new isn't your objective. We all are employed to create value. If your new invention doesn't create value, then your invention will not be worthwhile and you shouldn't expect your company to be enthusiastic about your "great" accomplishment – the non-value-adding invention.

In fact, the non-value-adding invention equals one thing – increased costs – and increased costs equal reduced profits and guarantee reduced R&D budgets!

Our nonwovens industry is growing and changing rapidly. New products and new, improved technologies are being introduced – some with perceived value, some with real sustainable value. However, our industry is also consolidating, even though some new companies are coming on the scene. So this can be a time your company might say: "This business is getting tougher – let's reduce costs to improve our financial performance." The first thing to get cut is usually R&D. Conversely, (and somewhat with tongue in cheek) the last thing to get cut is the CEO's compensation.

Albin Turbak	Retired
Larry Wadsworth	Univ. of Tennessee
J. Robert Wagner	Consultant

So how do you change this paradigm? It is simple: Create/invent things that have more value to the CEO than the CEO's compensation! I know there are companies that reward their R&D scientists by the number of patents that are issued. I am not saying that getting a patent issued is not a milestone, but the real test, the real payoff, is inventing something that results in a profit payoff for your company. So I believe companies should not reward R&D scientists for just creating something new and unique, but rather reward R&D scientists for creating something new and unique that adds value and adds to the profitability of the business.

Here are some new approaches to insure that management will support an increase in your R&D budget:

- Don't waste valuable time in blind alleys – know when to stop, to kill a program or project, and don't be afraid to give up … and move on!
- If the current development that is occupying your time dead ends in "stand-in-place-perpetual motion," then your are just wasting your company's resources, and it is preventing you from moving on to something else that could add value.
- Focus on tangible value at the expense of perceived value. It is true that if your invention has perceived value, that is better than no value – but the risk of perceived value is that it won't be long lasting. Although Barnum & Bailey made famous the saying, "there's a sucker born every minute," in today's rapid communication, perceived valued doesn't last too long. Fads change, hoaxes have short lives and competition is fierce.
- Don't ignore product cost – and the ease of manufacturing your invention.
- Understand (a) what your customer needs, (b) what their customers' need, and (c) what your business needs.
- Don't get enamored with patents for patents sake – your job is to create value.

If you take this approach, you will make your R&D spending more important in the achievement of your company's success and this will lead to increased R&D spending as you deliver results where they really count … in the profit column.

—INJ

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THE DIRECTOR'S CORNER

Worker Safety
Despite the fact that 1998 was a good year in terms of industrial safety, 17 working Americans died every day from industrial injuries. That is a situation that is hard to accept when so many resources exist for prevention and remediation.

Of course, there were unique circumstances involved in every case, in every accident and in every death. No amount of rationalization or explanation can remove or abate the stark reality of this situation, however.

Even though every Laboratory Administrator, Research Director, Plant Supervisor and everyone else with administrative responsibility begrudges the time, effort and resources devoted to safety and industrial hygiene, analysis of many accidents and "near misses" clearly show that unsafe conditions and unsafe practices can be eliminated by relatively little effort or change. A willingness to accept an unsafe condition or a risky procedure is often the source of such "crap shoots." Historical acceptance of unsafe conditions is too often an adequate explanation.

Dr. Scott Geller, an industrial psychologist who has focused on the relationship of behavior (industrial and laboratory) safety has provided the following items as the principal elements in workers accepting risk and taking chances:

1. 1. Does the worker know that safety precautions are expected?
2. Are there obvious barriers to safe work practices? (operating equipment, personal protective equipment, etc.)
3. Do workers receive behavior-based feedback related to their own personal safety?
4. Are people put down when they should be lifted up for safety actions?
5. What are the consequences for safe behavior?
6. What are the consequences for at-risk behavior?
7. Are there more negative than positive consequences for safe behavior?
8. Can safe behavior lead to soon, certain and positive consequences?
9. Does a worker receive more attention, prestige or status from co-workers for at-risk than safe behavior?
10. Are workers recognized individually and as teams for completing process activities related to

safety improvement?

As will be noted, these 10 questions in such analysis ask the critical questions: "Is safe behavior punished?" or "Is at-risk behavior rewarded?" From Dr. Geller's focus and other studies, the critical importance of expectations and consequences are readily apparent when they are implemented immediately and effectively. (Robert F. Mayer and Peter Pipe, "Analyzing Performance Problems," The Center for Effective Performance, Inc., Atlanta, Georgia).

Violence in the Workplace

Another safety factor that demands the attention of the Research Director and others in supervisory position is the matter of violence in the workplace. While many administrators feel this should not be their concern, current statistics in the United States proclaim otherwise. In 1998, 709 workers were murdered on the job, OSHA reports. That's the lowest total in the past seven years. In 1994, 1,080 on-the-job homicides were reported, the worst year on record.

Again, no guarantees can be provided in real world situations. There are steps, however, that the Research Director and Supervisors can take to lower risks and heighten awareness.

An analysis of contributing factors can be helpful. Personality conflicts were reported as the impetus in 55% of the cases, according to a recent survey by the Society for Human Resource Management. Other common causes include family or marital problems (36%) or work-related stress (24%).

Although OSHA has no specific standards directed toward preventing workplace violence the agency has offered some guidelines as follows:

1. Write a policy statement; although this will likely not cover all situations, it can provide useful guidelines.
2. Set up a threat assessment team; a group considering the eventualities on a regular basis can be very helpful.
3. Assess potential hazards.
4. Set up controls to prevent violence; this may involve a security system to control building access, as well as other steps.
5. Train and educate your workforce; a discussion of potential problems and situations can often bring problems to the surface.
6. Set up a system for reporting, investigating and evaluating incidents; this step can often reveal trouble spots.
7. Track reports and incidence through record keeping.

The last two items were stressed by OSHA as being sources of insight into remedial steps. They recommended the review of a broad range of reports, including incident reports, near-assault reports, medical records, insurance records, worker's compensation records, police reports, incident investigations, training records and grievances.

It is pointed out that employees can often be the best source for identifying high-risk areas and activities that are most vulnerable to acts of aggression. Further, they are often first to know of personality conflicts or off-the-job personal problems that could boil over at work.

It is important to keep in mind that workplace violence does not always result in injury. It's more than just incidence of physical assault — abuse, verbal attacks and aggressive behavior, pushing and shouting, for example — should be reported, recorded and investigated.

This is another area where a little common sense goes a long way.

Using ‘Attaboys’ and ‘Attagirls’

Turning from rather grievous items, a Research Director is still responsible for building a research team that will be a winning combination. Recruiting and retaining the right people is still a major task for the industrial and academic Research Director. The magnitude of this task is indicated by:

- 80% of the top executives at major companies spend 11 hours or more a week on recruiting, according to the *Wall Street Journal*; 52% of top executives spend more than 16 hours a week on recruiting.
- 68% of respondents to the "*R&D Magazine*/KSR Career Satisfaction & Salary Survey" report difficulty in filling vacant scientific or engineering positions.
- 53% of respondents say there are not enough qualified candidates, while 20% say there are too many unqualified candidates to sort through.

All of this indicates the importance of retaining those professional and technical people that are a valuable asset to the staff.

It always comes as a bit of a surprise to realize how important "work perks" —non-financial benefits — are to attract and retain people. In a recent study, the perks offered by a large number of industrial companies were surveyed, with the results reported in the box below.

In some specialized talent areas, the recruiting has become rather wild. Tales circulate of unique inducements being offered to computer programmers and specialistics, such as BMW automobiles and the like. However, it is generally much more economic and practical to retain desired talent rather than recruit it. So, what can a manager do to confirm to an employee his/her value to an organization. Current personnel management stresses the concept of "pay-for-performance." This position involves reward for contribution, not for seniority.

Another management concept that is being used effectively in many quarters is the use of simple but

A Laboratory Survival Manual

Safety in the laboratory is a special issue that requires special consideration and review. Dangerous materials are only handled occasionally, but a variety of hazards exist. Instruments, operating equipment and especially pilot plant environment create special situations where special evaluation is appropriate. As an aid in such an audit, the University of Virginia, Office of Environmental Health and Safety, has developed a series of laboratory safety guidelines. These have been incorporated in a collection entitled “Laboratory Survival Manual,” which presents guidelines for working with a variety of materials.

Topics in the manual include general laboratory safety, personal protective equipment, laboratory safety equipment, first aid and emergency procedures, properties of hazardous chemicals, special classes of materials, chemical labeling, material safety data sheets, and chemical waste collection. Specific programs cover asbestos, fire, radiation, ergonomics, gene therapy, industrial hygiene and other safety topics.

Although this safety manual cannot cover all topics of interest to specialized research laboratories, it does provide a very solid basis for discussion of basic lab safety guidelines. As such, it can be a very useful resource.

For more information: http://keats.admin.virginia.edu/lsm/home.html.

Most Frequently Offered Perks *(% of Companies Offering Them)*	
Casual Dress	82%
Flexible Hours	61
Personal Development Training	49
Employee Entertainment/ Product Discounts	40
Free Food/Beverages	36
Telecommuting	27
Fitness Centers	16
Recreation Facilities	9

imaginative low-cost rewards by way of showing appreciation and providing recognition. This is based on the time-honored principle that "what most motivates the people who work for you is recognition."

One management specialist has taken this concept to the point of writing a very interesting book entitled "1001 Ways To Reward Employees." The message of this effort is that it is the thoughtful, personal kind of recognition that signifies true appreciation for a job well done, for going the "second mile." The author says this is "thinking past the raise and the promotion."

Some examples:

- Workers who must stay late at Time Inc. get cab fare home.
- Marion Laboratories annually takes all employees and guests to see a Kansas City Royals game.
- Chevron keeps a Treasure Chest brimming with gifts so supervisors can reward employees on the spot.
- Home Depot’s Employee-of-The-Month Award gives honorees $100 and a merit badge — and engraves his or her name on a plaque.
- At Busch Gardens-Tampa, employees who offer exceptional service to guests receive a "scratch-off" card yielding various awards.
- Every Christmas, The Walt Disney Company opens Disneyland for employees and families only — with executives running the park.
- The morning after a product passed a crucial test at Odetics, a mariachi band paraded through the plant, followed by clerks from the local Baskin-Robbins franchise offering free ice cream.

Obviously, there is another area where a little ingenuity goes a long way. ("1001 Ways To Reward Employees," by Bob Nelson; published by Workman Publishing, New York. 1994)

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RESEARCHER'S TOOLBOX

The needs of nonwoven researchers and technologists are often very specialized. The usual scientific and engineering tools can frequently serve these specialists, but at times a new device, technique, method or skill is required by the nonwovens expert to do the out-of-the-ordinary. This section is provided to highlight a variety of such items, in the hopes that they will prove useful and make the job of the researcher more effective.

Computer Programs for Conversions and Calculations

There is an array of property units used within the nonwovens industry. A basic property, such as fabric weight or basis weight, might be expressed in grams per square meter (gsm) at one time or place, and then in ounces per square yard (osy) at another. Often within the same company, a variety of fabric weight units are used; sometimes the Operating Division uses a different unit compared to the Research Division or the Sales Division.

Some of this variation stems from the different origin or "roots" of various segments of the industry. People in the wetform process segment of the industry often use basis weight units that are derived from the paper industry. "Pounds per ream" are often quoted by these people; unfortunately, they don't all talk about the same size ream (different standard for sheet size, number of sheets, as well as area based on square feet, etc. for some categories).

A dryform process plant with historical ties to the conventional textile industry may use the osy system or even "grains per square yard" (grains, harkening back to yarn manufacture). In some quarters there is even a mixture of units, such as "grams per square yard" or worse.

Technically, the United States is supposed to be committed to a movement to "The International System of Units," which is abbreviated as "SI" (from the French name, Le Systèm International d'Unités) in all languages. This move is observed much more in the breach than in the use, unfortunately. This leaves the U.S. and one small island country as the sole hold-outs to extensive use of SI.

Reference is frequently made to "English" units in these matters, but such units are now very rare in England; as a result, such terms are now often referred to as "The American System" in many places, although there is still little agreement within the U.S.

As a result of this strange mixture, there is frequent need for conversion of units from one system to another. While there are a variety of conversion tables floating around, these often are a frustration, as additional calculation and manipulation is generally required.

A computer program that provides extensive and simple conversions, and has gained much favorable comment, is one coming from roots within the Canadian pulp and paper industry. This program, "WinMetric," provides an easy and fast program to make routine and complex conversions. It has the added advantage that the user can insert customized conversions to supplement those originally included in the program. If someone want the basis weight in Troy ounces per square foot, it can be inserted into the program as a routine factor.

The program goes much beyond direct conversion capabilities, however. A value needed in another document can be stored on the "clipboard" and pasted later into any document. The number of decimal places in an answer can be designated, so that the precision of conversions can be controlled. In addition to the common unit conversions feature, this program also has a section of specialized support files for industry-specific units, such as pulp and paper industry units of Burst Index, Tensile Strength and other units of considerable use.

The WinMetric Program also goes beyond direct conversion use. There is a section on the Periodic Table of the chemical elements, with a dozen widely used properties of each element.

SI and American steam tables are incorporated in the WinMetric Program. In this case, the user selects from Saturated (pressure), Saturated (temperature), Superheated steam or air for the values of interest. Another section contains Properties for moist air (psychometric) calculations.

A scientific database sits in another section of the program. This has a selection of equations, constants and properties, which can be augmented by customizing, in order to store frequently used scientific data and equations beyond the significant selection already provided in the program. This feature permits customization of the program to suit the specific interests of the user, and greatly enhances the value of the program. By running the program in the background and providing a "hot button," a couple of simple clicks or key strokes put considerable useful power at the finger tips.

WinMetric requires Windows 3.1 or higher, a mouse, with a VGA or better screen. At least 8Mb of RAM are required for most users to be able to run the program conveniently. The program sells for less than $100. A demo disk with a trial life of 30 days is available from Drying Doctor, P.O. Box 63134, Verdun, Quebec H3E 1V6, Canada; 514-767-3897; winmet@microtec.net; www.microtec.net/~winmet.

Another interesting program is the Golder Associates GUN Units-Converting calculator. This is a scientific calculator that can automatically convert units. The user enters a formula into the input field, following each value by its units, in braces. The units desired for the results in then entered, or else the units are selected from a default list. GUN has a large number of built-in units and scientific constants.

In addition, the user can add their own units and constants, and can save and retrieve their formulas. The program helps to prevent errors by ensuring that units are compatible, and by displaying the result only in valid units. The GUN formulas can reference a library of trigonometric, mathematical, statistical and financial functions.

The GUN program is available free of charge. It runs on 32-bit Windows systems, such as Windows 95, Windows 98, and Windows NT. It is available from Golder Associates Inc. (4104 148th avenue N.E., Redmond, WA 98052; 425-883-0777; Fax: 425-882-5498). Or download: http://www.golder.com/gun/ (1,478 K with DLL libraries from Microsoft Foundation Classes).

Electronic Laboratory Notebook

Any researcher who has been involved in court testimony regarding his or her laboratory notebook knows the stringent guidelines involved in maintaining an accurate, complete and well-documented record. With increasing regulatory requirements and the growing importance of patents to the industry, nonwoven researchers would do well to be sure of their laboratory practices in this regard.

To be able to withstand the assault of opposing attorneys, patent examiners, government regulators, and even one's own company legal department, well-established procedures must be adhered to very carefully. The details of the experiment or run must be sufficient to allow another scientist or colleague to fully duplicate the experimental work and build on the experiment for future developments.

The basic requirements include handwritten entries in permanent black ink, recorded in a bound notebook with consecutively numbered pages. The writing must be clear and legible. Mistakes are never removed or blanked out by correction fluid; rather, the error is crossed through and replaced by the correct data and the correction initialed.

The objective and experimental details are outlined, with sufficient information to establish the purpose of the work. Materials used (fully identified as to source), process conditions employed and full details of the work in sufficient detail to allow repetition and full identification are required. The use of codes or abbreviations should be clearly explained somewhere in the notebook or within the description.

An index and means of cross-referencing the work should be provided. Imagine trying to locate in your old notebook and fully identify under critical and stressful conditions an experiment which was carried out five years ago. At times such as those, a well designed and complete indexing and referencing system would be so gratefully appreciated.

In this era of computers and laser printers, it seems a real burden to carefully write by hand the full details of an experiment or trial run. Further, there is so often the cut-and-paste chore of inserting into the laboratory notebook the primary data collected from instrument recorders, computer printouts and other sources.

A seemingly simple solution to this onerous task is to use the computer or similar electronic device to function as the laboratory notebook. A little reflection on this proposal, however, reveals many problems in meeting the stringent legal, regulatory, technical and societal requirements for achieving an acceptable substitute for the traditional laboratory notebook. Easy replacement of written material in a document is a boon for a word processing program, but is completely unacceptable for a laboratory record.

Considerable effort is being applied to this problem, however, because the advantages of using a computer-based system are very sizable. Not only is there a distinct convenience to the researcher, but work stations outside the laboratory could be benefitted. Also, multiple sites could have easy access to the record. This would be especially meaningful to multi-national companies and companies with widely separated research, marketing and production sites. Easy retrieval would also be a tremendous help.

One system that has been developed and is in use on a limited, trial basis involves the use of special notebook paper that is accompanied by documentation procedures; these procedures allow scientists to use currently available electronic technologies. Document integrity has been designed into this system, which allows the use of computers and laser printers; this makes it rather easy to collect data from a variety of sources and insert these data into the laboratory record. This document paper and recording system is called the "PatentPad" system.

This system is relatively simple in practice. When the scientist wants to record the daily research data, individual sheets of PatentPad paper are laser printed and then signed, dated and witnessed. Each sheet is a part of a large systematic recording procedure involving a unique paper designed for each corporate user and backed by multiple layers of behind-the-scenes documentation for record corroboration. In essence, this system provides document verifiability and integrity by means of the unique corporate visual and numerical fingerprint that serves as identifiers for each sheet of the system paper.

Because the data are generated electronically, the dissemination of the records in an electronic format can be done at the same time the data are sent to the printer. This hard copy generated by the printer replaces the bound book and is used for the archival copy. The PatentPad system is a product of SCRIP-SAFE Security Products, (Joe Orndorff, President, 11319 Grooms Road, Cincinnati, OH 54242).

As an indication of the interest in this work, an association exists to coordinate and promote the effort. This is the Collaborative Electronic Notebook Systems Association (CENSA, Dr. Rich Lysakowski, Executive Director, Woburn, MA; www.teamscience.com). Several large multinational companies are a part of CENSA, as well as several government organizations. Industrial and government organizations from overseas locations have also become members of CENSA. Vendor companies have recently been added to CENSA; the initial company is PSSoftware (www.PSSoft.com).

With the total effort that is going into this activity, it is apparent that an electronic lab notebook and knowledge management system within the research laboratory is not too far in the future.

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EMERGING TECHNOLOGY WATCH

It is relatively simple to look backward over the past decade and to spot the genesis and evolution of today's latest products or process, even today's latest fad. However, to look ahead into the future and see the same constituents that will be useful, well accepted and profitable is not nearly as easy.

In fact, it is very difficult, as every forecaster knows. Sometimes a scanning of the horizon reveals small blips that foretell a certain development that will have major consequences in the fairly near future. These few pages are based on that hope.

Color Me Green
The preference in color is well recognized to go through cycles and changes. The apparel industry has its color consultants who specify the fashion colors for each changing season. The automotive industry likewise comes up with some new colors for each production year to add to the old basic white and black colors.

If there is a universally preferred color today, it would seem to be green. Not just ordinary "green" green, but the green that brings to mind the environment, "growing" green, the green that shouts that it is environmentally correct, that it is recyclable, that it gives the right bottom line in Life Cycle Analysis.

The chemical industry has focused on this concept by a concern with "Green Reactions" or green processes. These are reactions carefully designed to use environmentally friendly reactants and replenishable reagents, yield by-products that are benign or reaction conditions that have a low energy expenditure.

The nonwovens industry and nonwoven technology are also conscious of the desirability of products, processes and practices that are environmentally sound, use replenishable components and have little troublesome waste. This industry is particularly concerned with ease of disposal under realistic and environmentally friendly conditions.

A potential key element in this quest for a truly "green" nonwoven product may be rapidly emerging. This approach depends on a new type of polyester fiber based on polylactic acid (PLA) instead of terephthalic acid. Because the PLA can be derived from a variety of agricultural-based starting materials, this monomer is truly replenishable

Potential primary feedstock include wheat, rice and agricultural waste in addition to corn, the prime source of dextrose or glucose. This intermediate is produced by hydrolysis of the green plant material. The lactic acid is derived from this carbohydrate material by a fermentation process. The lactic acid is then reacted into lactide ring intermediates; with metal catalysts, the lactide ring can be opened with one or more polyols to yield the polyester product.

By using various polyols and reaction conditions, a variety of polyester resins can be produced. It is claimed these resins can produced a range of products that equal the in-use performance of the more conventional PET polymers. Importantly, the good performance is also matched by comparable cost advantages, resulting in actual cost/performance advantages. The relative ease of biodegradability, as well as the sustainability nature of the raw materials for PLA polyester are also important pluses for this material.

The first commercial-scale production unit for polylactide polymer has been announced by Cargill Dow Polymers, the 50/50 joint venture between Cargill and Dow Chemical. This will be a 300 million pound per year unit being constructed at Cargill's processing complex in Blair, NE, close to the source of corn raw material. The plant is scheduled to come onstream during the later part of 2001. The two parent companies have indicated they intend to build a European production facility as soon as the North American plant is operational, and then build additional plants in various parts of the world.

Fiber products and packaging applications are being targeted as the initial outlets for this green resin. The fibers are stated to be very suitable for apparel and carpet applications. In carpets, it is stated that both the backing and the face can be constructed from the PLA fiber, allowing easy recycling. The primary packaging applications are indicated to be packaging films, thermoformed food and beverage containers and coated paper and board products.

As to nonwoven applications, some extensive research and development work has been carried out and is continuing, especially in the spunbond and meltblown processes. Some product patents have issued and process work is continuing on several fronts.

PLA is not the only candidate for a new raw material for nonwoven production. Within the polyester family of materials, there is concerted research and development being devoted to other structures, some of which have an agricultural or fermentation basis for production. Some of this is directed toward the polyacid component and some toward the polyol component of polyester monomers, whereas other work is being focused on other hydroxy acids, to incorporate both functions in the same molecule. Various shades of "green" are involved in these diverse efforts.

In the future, a "nonwovens plant" may denote something rather different than it does today.

Strategic Technologies
for the Year 2020

Forecasting beyond one year is a pretty perilous activity. Forecasting beyond a decade can be downright absurd, but people do it nonetheless. Recently, a group of top scientists and engineers at Battelle Memorial Institute in Columbus, OH compiled a listing of the 10 top technological trends that will impact society over the course of the next two decades.

Stephen Millett, Battelle's Thought Leader and Manager of Technology Forecasting, commented with the publication of the listing, "The 20th Century was the time of big technologies, mass production, mass wars, and mass politics. But for the years ahead, new technologies will become much more personalized, and they will closely affect almost every aspect of our lives."

Millett further added, "We see advances in information and biological technologies bringing us into a more intimate relationship with nature and with each other. From cloned human organs, to personalized public transportation, to computers and sensors embedded in our bodies, we will become intertwined with technology."

The Battelle List includes the following technological features:

1. ***Genetic-based Medical and Health Care***. Medical technology originating from genetic research will provide the ability to detect and correct many genetic-based diseases. New pharmaceuticals from biotechnology research will provide new cures and preventative measures.
2. ***High-power Energy Packages***. With the development of highly advanced batteries, inexpensive fuel cells and micro-generators of electricity will make many electronic products and appliances highly mobile. Decentralized power sources will be extensive, affordable, and environmentally clean.
3. ***Green Integrated Technology (GrinTech)***. The prediction is that GrinTech will be especially important in agriculture, mining, manufacturing, and transportation systems. Fears of global climate change and mountains of garbage will thrust environmental concerns to the forefront of consumers and industry around the world. The prediction is that technology will provide the answers via new systems that eliminate rather than reduce waste.
4. ***Omnipresent Computing***. As might be expected, this prediction foresees computers everywhere and in everything. The use of very miniature, wireless, highly mobile, powerful and highly personalized computing will provide extensive networking, access and constant contact. Computers will be embedded in our clothing and possibly implanted under our skin.
5. ***Nanomachines.*** These microscopic machines will revolutionize several industries and may perform a wide range of jobs, from such things as heating homes to detecting cancer. Nanomachines are measured in Angstroms, rather than millimeters. They may be able to go into the body and carry out very specific assignments.
6. ***Personalized Public Transportation***. A high demand for personal vehicles will be maintained, especially because of the aging of the population, coupled with concerns about safety, convenience and independence. The continuing growth of cities will further stress the transportation infrastructure, which will result in coordinated and optimized public transportation networks.
7. ***Designer Food and Crops***. Genetically engineered foods that are environmentally friendly and highly nutritious will become commonplace. Engineering of crops that resist diseases and pests will reduce the need for pesticides. Industrial agricultural crops will also benefit from this trend.
8. ***Intelligent Goods and Appliances***. Amazing intelligence will be added to appliances and other products by the advances in quantum computing with smaller and smarter elements. Telephones with extensive capabilities will be networked with such appliances and goods, providing a wide range of control and convenience.
9. ***Worldwide Inexpensive and Safe Water***. Before water shortages become very much more critical, technology will answer the challenge of clean drinking water at a reasonable cost. With advanced filtering, processing, and delivery using desalination and water extraction from the air, plentiful and inexpensive clean water will be made available.
10. ***Super Senses***. Virtual reality will expand, and be augmented by "enhanced reality." Using sensors,

and electronic/genetic technology it will be possible to implant devices that will allow improved hearing and seeing, as well as facets of the other senses.

While some of these predictions are rather unreal and based on imaginary concepts, others of these developments seem within realistic reach. With a little innovation, each of these developments can be visualized to entail the use of nonwoven materials in the future.

More information on these forecasts can be obtained directly from Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio 43201; 614-424-6424; www.battelle.org

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NCRC Bringing Entire Nonwovens Industry Together

Cooperative research consortium at North Carolina State

http://ncrc.ncsu.edu/

It is generally accepted that the nonwovens industry is a unique business, one that plays a highly important role in so many aspects of our society today yet remains virtually unknown to anyone outside of the few who work in and around it. Toiling in relative anonymity is a way of life for many involved in the business of nonwovens research, yet their contributions have been vital to advances in fields as diverse as medical fabrics and civil engineering.

Within the nonwovens research community there is an even more unique group that has blossomed over the past nine years. Sensing a need for cooperative research among industry and academia, in 1991 major companies and research institutions put aside their differences and formed what has become a true industry partnership. Today, membership in NCRC is open to companies Worldwide.

A Lot In A Little Time

The Nonwovens Cooperative Research Center (NCRC) was established early in the 1990s through matching grants from the National Science Foundation, the State of North Carolina and, more importantly, 19 member and affiliate companies. Its sole purpose: "To help strengthen the global competitiveness of the U.S. nonwovens industry through a coordinated, industry-monitored program of research, both fundamental and applied, education and technology transfer."

The results in one short decade have been nothing short of remarkable. Subhash K. Batra, co-director of NCRC, along with Benham Pourdeyhemi, who joined last year, reports that since NCRC's inception, faculty and staff have graduated 18 MS and 14 Ph. D. students, published more than 90 papers (quite a few in this *International Nonwovens Journal*), and made over 90 paper and 28 poster presentations.

"The Center aspires to become the premier institute devoted to fundamental and applied research toward understanding product characterization and process technologies that will benefit the U.S. nonwovens industry," says Pourdeyhemi in explaining NCRC's mission.

Adds Batra: "We look to equip ourselves to play a key role in assisting the industry in product development by making available the best laboratories as test bed facilities and by providing consulting services, specialized product testing and evaluation, educated 'people' power and on-site education to those members of the industry who seek it."

Two-Pronged Attack

The NCRC program attacks the industry problems in two ways - as core and non-core research. The core program contains three thrusts centered on product performance, process development and analysis and materials application/development, which are key ingredients in successful product development. In its core research NCRC does not engage in product development.

The center also pursues non-core research projects sponsored by companies looking for solutions to certain problems on either a proprietary or non-proprietary basis. The results of this research are the property of the sponsoring company or companies within the university's guidelines.

The results of both of these efforts have been impressive. Among the litany of successes in the past decade:

- A theoretical model has been developed to predict uniaxial and biaxial stress-strain behavior of point bonded webs using nonlinear stress-strain properties of the constituent fibers, fiber size, ODF and basis weight of the fabric. This Mi-Batra model is being used in on-going research relating to thermal bonding geometry and process parameters to final properties of the fabric.
- A comprehensive Image Analysis System has been developed to analyze the structural and physical characteristics of nonwoven fabrics. This copyrighted software has been customized and licensed to several member and non-member companies.
- A method to study the transmission of micro-organisms through surgical fabrics has been developed using confocal microscopy. It is a tool for medical nonwovens manufacturers to evaluate the barrier properties of their fabrics in protective garments.
- A unique biaxial load-deformation measurement device has been developed and tested for its usefulness. Its commercialization is imminent. In critical applications fabrics are subject to biaxial loading. Few devices are available to measure biaxial behavior; those available have limitations when it comes to nonwovens.
- A correct method to measure fiber structure core-to-skin for circular fibers using interference microscopy has been developed. It has been used to study the influence of fiber structure variation on the efficiency of heat activated bonding between two thermoplastic fibers. The results obtained for PP and PET fibers have profound implications for improving the efficiency of thermal bonding processes widely practiced in the industry.
- Another study has established the probabilistic nature of web formation with the development of models to calculate mean and variance of fiber intersections of fibers of varying lengths, straight or crimped. The models yield practical insight into what constitutes the best achievable two-dimensional uniformity as a function of fiber geometry and basis weight of fabrics. Such information is essential for developing a sound statistical basis for process control.

- A completed study relates to unraveling/improving carding technology. In addition to identifying significant factors influencing mass uniformity of the carded web, a device to measure openness and mass uniformity of the card feed mat on-line has been designed and a notice of invention has been filed. While its implementation on a commercial scale requires further development, when implemented it has the potential to control cross machine uniformity of the carded web, thereby yielding improved quality products.
- An ARO-MURI project is aimed at developing protective systems for soldiers of the 21st Century. As part of the project, an NCRC group of investigators has been engaged in developing technology for "Functionally Tailored 3-D Textile Structures Through Meltblown Technology." A meltblowing three-inch die has been integrated with a seven-axis robot to spray fiberwebs onto foraminous molds to form seamless parts of garment systems. The system is under further development to make complex structures with controlled property characteristics. Eventually it is expected to become part of a complex manufacturing machine system incorporating many materials and features.
- The use of cotton in wetlaid nonwovens has been nonexistent. A method for dispersing cotton (comber noils) and wood pulp mixture was developed that showed the feasibility of using cotton in wetlaid nonwovens for medical use.
- To improve the design of carding machines, it is important to understand the fiber transfer efficiency at various points in the process. Accurate measurement of the transfer efficiency of different elements of the carding machine has been next to impossible. Using IR photo diodes, instrumentation to measure fiber loading (fiber mass/unit area) on cylinder and doffer has been developed. The measurements allow calculation of transfer efficiencies on-line.
- The structure of the web in terms of orientation distribution of fibers controls physical/mechanical properties of the web. NCRC, using laser diffraction technology in conjunction with the image analysis, has developed a system to measure the orientation distribution for lightweight nonwovens. The system is being commercialized for on-line process control.
- A mechanics-based mathematical model of three-dimensional webs has been completed. It predicts elastic properties of the web based on fiber size, fiber modulus, mass density of the web and ODF representing the web structure.

NCRC Member Companies
3M Company
Albany International
Asten Johnson
BBA Nonwovens
Buckeye Technologies
Celanese Acetate
C.H. Dexter
CHA Technologies
Cotton Incorporated
Dow Chemical Co.
DuPont
Eastman Chemical
FiberVisions
Freudenberg Spunweb
Goulston Technologies
INDA
John D. Hollingsworth on Wheels
Kimberly-Clark
KoSa
PGI Nonwovens
Procter & Gamble
Wellman

Affiliate Companies
Biax-Fiberfilm
Eldim

Heading to the Future

NCRC is certainly not ready to rest on its laurels. As a natural extension of its current activities, NCRC is establishing a unique Melt Extrusion Laboratory incorporating a two-beam bicomponent "Multi-Purpose" SpunMelt line to produce both spunbond and meltblown fabrics together as a composite or individually.

The bicomponent dies allow side by side, islands in the sea and other bicomponent varieties not previously available on a SpunMelt machine, a very significant capability. It allows the engineering of a new class of fabrics composed of very small fibers or specialty functional fabrics by using multiple materials in the same structure. The line will have the capability to run hydrophobic, hydrophilic, bio-degradable, adhesive polymers, elastomeric, engineering polymers (alone or in combination), with the ability to switch from one to the other quickly. Flexibility is the overriding characteristic of the proposed laboratory. The addition of this facility will allow NCRC to serve a wider sector of the industry. — *Michael Jacobsen*

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INJ DEPARTMENTS

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PATIENT REVIEW

On December 7, 1999, the United States Patent and Trademark Office issued U.S. Patent 6,000,000. While not the same as Millennium 2000, this patent does represent a landmark of sorts.

Since the first U.S. patent was issued in 1790, this office has mirrored the introduction of new ideas, new products, new processes, new designs, new plants, and more recently, new life forms.

An estimate was made when U.S. 5,000,000 was issued on March 19, 1991; at the rate of patent issuing at that time, it was judged that the next million U.S. patents would require a little less than 14 years. Actually, this event occurred in a little less than nine years, a clear indication of the increased tempo of technical innovation.

Not surprisingly, U.S. 5,000,000 was involved with gene development and biotechnology, while U.S. 6,000,000 was directed toward computer systems and hardware.

The suggestion was seriously offered in the 1890's that the U.S. Patent Office be closed, as it was obvious that virtually everything possible had been invented. A safer prediction today is that the next million U.S. Patents will come in about six years or less.

Changes in U.S.
Patent Office Practice
After a variety of aborted attempts and four years of efforts, major patent reform legislation has been enacted by the U.S. The finished work, identified as public law 106.113 (November 29, 1999), involves numerous changes which have been described as "the most important and most comprehensive reforms to our nation's patent system in nearly half a century," according to Senator Orrin Hatch, Chairman of the Senate Judiciary Committee.

Several features of the new law are worth noting: There is a limited defense provided an inventor against infringement claimed in a method that is being patented by another party. It also provides an optional re-examination process at the Patent and Trademark Office (PTO) for reviewing a patent's validity.

The new law also extends the life of a patent if processing of the patent application is delayed for reasons beyond the inventor's control. An important change in the patent law is that U.S. patent applications also filed abroad will be published 18 months after filing in the U.S. This new policy is designed to allow American inventors the opportunity to see the technology their foreign counterparts are seeking to protect at a much earlier point than today.

This practice of publishing applications 18 months after submission, and before final approval of the patent, is a standard practice in most countries throughout the world. However, the new law does not harmonize U.S. patent practice with that of the rest of the world by requiring publication of all U.S. patent applications 18 months after the initial filing date.

Attempts to make the PTO completely independent of the Department of Commerce were not successful. Under the new law, the PTO will still be an agency of the commerce department, but it will exercise independent control of its budget allocations and expenditures, personnel decisions and other administrative and management functions. As a part of these changes, the PTO will reduce patent fees, while raising trademark fees.

Another innovation at the PTO, not a part of the new law, is the extension of their electronic filing system. This system allows the acceptance of patent applications via the Internet. PTO has permitted trademark customers to file applications on the Internet for the past year, as such applications are not considered quite so sensitive. Biotechnol-ogy patent filings are currently the only ones that can use the Internet, but PTO plans to expand the service to most other patent filings during the year 2000. A fail-safe system to protect the confidentiality of such applications has been the critical element to be established within such a system.

With this improved Internet safety, PTO has also recently launched their Patent Application Information Retrieval system (PAIR), which makes it possible for applicants and their designated agents or attorneys to securely obtain up-to-the-minute information on their pending or abandoned applications. PAIR makes it possible to quickly access patent application data, including current status of the application, in a few mouse clicks without compromising the confidentiality or security of pending or abandoned applications.

RECENT PATENTS
Hydrophilic Fiber Finish
A composition to provide an excellent, permanent hydrophilic finish to polyolefin fibers and filaments is disclosed. The composition has excellent hydrophilizing properties and excellent cohesion effect and good antistatic properties. When diluted with water, the compositions can be particularly useful as spin finishes for the permanent hydrophilizing of polyolefin fibers and filaments, as well as nonwoven webs produced from polyolefins.

The composition contains 15 to 75 parts by weight of at least 1-nonionic surfactant, and 25 to 85 parts by weight of at least one quaternary ammonium compound and/or at least 1-cationically modified polydimethyl siloxane.

U.S. 6,008,145 (December 28, 1999); filed

Ten Top U.S. Patent Grantees

The United States Patent and Trademark Office (PTO) has announced the top 10 private sector patent recipients for the 1999 calendar year. Listed below are the 10 corporations receiving the most U.S. patents for inventions in 1999, along with their ranking last year. For the seventh straight year, IBM received more utility patents than any other private sector organization.

The 10 organizations with the most patents in 1999 consist of three U.S. corporations, six Japanese corporations, and one corporation from the Republic of Korea.

Rank in 1999	# Patents in 1999	Organization
1	2,756	IBM

November 4, 1997. "Composition for the permanent hydrophiliation of polyolefin fibres, use of the composition and fibres treated therewith." Assignee: Schill & Seilacher GmbH & Co. Inventors: Zang-Ju Dzen, Christine Wild.

2	1,842	NEC Corporation
3	1,795	Canon Kabushiki Kaisha
4	1,545	Samsung Electronics Co., Ltd.
5	1,409	Sony Corporation
6	1,200	Toshiba Corporation
7	1,193	Fujitsu Limited
8	1,192	Motorola Inc.
9	1,153	Lucent Technologies Inc.
10	1,054	Mitsubishi Denki Kabushiki

As might be anticipated, Kimberly-Clark Corporation again led the industry in the number of nonwovens process U.S. patents obtained during the year.

Spunlace Airlaid Pulp Fabric
This patent discloses a method for producing an airlaid pulp fabric by a combination of a pre-bonding step followed by high pressure water entanglement.

A fibrous web is airlaid from woodpulp fiber or woodpulp fiber blended with shortcut rayon fiber. The web is then prebonded by sequentially adding moisture to the upper surface of the web and then calendering the web using a heated roll on the wetted surface. The lower surface of the web is then treated with a small amount of moisture and calendered with the hot roll adjacent to the wetted surface.

This partially bonded pre-web is then subjected to high pressure waterjets. This provides a web with good absorbency, softness and strength. In addition, the process has reduced fiber wash-out during the high pressure water treatment, compared to processing without the prebonding step.

U.S. 6,007,653 (December 28, 1999); filed November 26, 1997. "Manufacturing method and nonwoven material." Assignee: UPM-Kymmene Oy. Inventors: Pentti Pirinen, Tapio Niemi.

Splittable Composite Fiber
The high pressure waterjets of the spunlace process have become rather popular for the splitting of composite fibers as a method for forming many extra fine fibers from such a composite fiber. This disclosure describes a composite fiber with improved splittability characteristics.

The fiber is formulated so that the improved splittability does not lead to problems of pre-mature splitting in the carding or webforming stages of the process.

This selectivity in the splitting nature is achieved by having a composite fiber cross section wherein a part of at least one of the resin components of the composite fiber projects from the surface of the fiber. This projection on the fiber surface is very effective in engaging the high pressure water stream, which then initiates and fosters the splitting of the fiber into individual microfiber segments during the spunlacing step.

A variety of fiber cross sections are suggested in the patent disclosure. Each one of the special cross sections has at least one resin component projecting from the surface of the fiber to engage the waterjet during the splitting operation.

U.S. 6,004,673 (December 21, 1999); filed March 23, 1998. "Splittable composite fiber." Assignee: Chisso Corporation. Inventor: Masaru Nishijima.

Bicomponent Polyolefin Staple Fiber for Thermobond Web

This patent discloses a polypropylene bicomponent staple fiber specifically engineered for the production of nonwoven fabrics by the thermobonding process. The fabric resulting from this system is claimed to have improved properties with respect to mechanical isotropy and softness.

The fiber is obtained from a polymer mixture consisting of 85-99.9% by weight of polypropylene homopolymer or polypropylene copolymer of the type normally used in the correction of thermobondable fibers, and of 0.1-15% by weight of polyethylene. The invention also discloses the use of nonwoven fabrics from such a polyolefin fiber converted into a laminate composite product comprising a layer of such a nonwoven web coupled to a polyolefin film.

WO 99/55942 (November 4, 1999); filed April 29, 1999. "Polyolefin staple fiber for the production of thermally bonded nonwoven web." Assignee: Meraklon S.P.A. Inventors: Leonardo Pinoca, Giancarlo Amadio.

Modified Meltblown Process

This patent discloses an apparatus and a process for producing meltblown fibers. The process is more energy efficient than that using conventional meltblown apparatus and meltblowing die, and improves the uniformity and strength of the resulting product.

The modified system uses relatively cold, pressured air to assist in the drawing or attenuation of the fibers to the desired final diameter. A relatively small flow of hot air is used to shroud the inner die tip that carries the polymer. The cold air stream shrouds and surrounds the hot air shroud. The hot and cold air streams combine to provide a quicker fiber quench, while allowing the cold air stream to draw the fibers a greater amount. In addition, the flow paths of the hot and cold air streams converge at the die tip to result in a minimum amount of turbulence. The flow paths are substantially parallel, so that when they combine at the die tip the flow thereafter will be relatively symmetrical with little turbulence and fiber vibration resulting.

In addition to typical small diameter fibers, the present "co-flowing" invention allows the production of larger diameter fibers, when desired. The invention reduces the heat input and thus reduces the heat to be removed for quench of the fiber. The forming distance between the die tip and the web forming collector can also be reduced because the fibers are reduced in diameter faster.

U.S. 6,001,303 (December 14, 1999); filed December 19, 1997. "Process for making fibers." Assignee: Kimberly-Clark Worldwide, Inc.

THE NONWOVENS NET

PaperBase Database

An agreement between TAPPI and Paperbase International now allows TAPPI members to arrange special access to the Paperbase International extensive database, called "PaperBase." Paperbase International is a consortium of the four leading pulp and paper institutes in Europe — CTP (France), KCL (Finland), Pira International (UK), and STFI (Sweden). The consortium was organized with the aim of combining their various databases in order to provide their memberships with full coverage of the latest technical, research, and business information for the pulp and paper industry.

With this new agreement, TAPPI members can obtain subscription to this database at a 20% discount off the annual subscription via the Internet. In addition, TAPPI members can subscribe to the PaperBase CD-ROM with a networking license at the same price as the single-user license — a 30% savings.

An introductory offer includes access to PaperBase on the Web, free of charge for a limited time. For more information, www.paperbase.org or www.tappi.org.

Inventors: Bryan D. Haynes, Jeffrey L. McManus, Rick Bushy.

SMS Barrier Fabric
With Electrostatic Charging

This patent describes a steam sterilizable nonwoven material comprising a layer of spunbond fabric combined with a meltblown fabric or, alternately a tri-laminate structure of spunbond/meltblown/spunbond in a typical SMS construction.

The method involves charging of one or more layers of the laminate, particularly electrostatic charging, and then steam sterilizing the nonwoven material. The nonwoven material may be subjected to charging followed by steam sterilization or steam sterilization followed by charging.

One layer of the nonwoven material may be charged prior to forming the laminate. Also, one layer of the material may be treated with the appropriate anti-static material before or after subjecting the nonwoven layer to electrostatic charging.

Information on Standards

A useful site in searching out standard test methods and industry standards has recently been posted by CSSinfo of Ann Arbor, MI. This company distributes engineering standards, books and publications on standard test methods to clients and the general public. These standards are available in print or electronic formats.

This site provides information on hundreds of standards organizations, including ANSI, ISO, ASTM, British, German, federal, trade organization standards and others. The site can be searched by organization, standard title, key words, industry or standard number. In addition, the site provides helpful checklists which can be of assistance in interpreting and complying with federal and other regulatory agencies. (www.cssinfo.com). — INJ

U.S. 5,998,308 (December 7, 1999); filed May 22, 1996. "Nonwoven barrier and method of making the same." Assignee: Kimberly-Clark Worldwide, Inc. Inventor: Bernard Cohen.

Breathable, Barrier
Meltblown Nonwoven

This invention relates to a method for making a breathable meltblown fabric having enhanced moisture barrier properties. It is claimed that by using this method, a meltblown/spunbond laminate with improved hydro-head performance (for example, greater than 40 millibars or 16 inches of water) can be produced.

The disclosed process involves separately applying a secondary process to the meltblown web prior to lamination to the spunbond web. This secondary process involves passing the meltblown web through the nip of two smooth rolls maintained at an elevated temperature and pressure. An appropriate residence time in the hot nip results in the superior barrier component. The inventors suggest that this results from increased crystallinity of the microfiber web developed as a result of this treatment.

WO 99/57355 (November 11, 1999); filed May 3, 1999. "Method of making a breathable barrier meltblown nonwoven." Assignee: The Dow Chemical Company. Inventor: Osborne K. McKinney.

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WORLDWIDE ABSTRACTS AND REVIEWS

A sampling of Nonwovens Abstracts from Pira International

Fibre mixing non-uniformity assessment

The non-uniformity of mixing of fibres of different components and fibres in which one component differs in properties from the others is considered mathematically in relation to the two main mixing methods, i.e. organized and random mixing, under the headings: mixing density gradient, gradient of mixing unevenness, and entropy of mixing. Formulae are given under the first heading involving the variables: % deviation of the real composition from the recipe for different mixture volumes, under the second heading, the square of the non-uniformities of distribution of the components in different mixture volumes, and in the third, entropy heading, the % content of fibres of a particular component, and numerous other variables.

Author: Sevostyanov AG; Kosygin a AN
Source: TEXIN
Issue: no. 7-8, 1999, pp 22-23 (In Russian)

Porous polytetrafluroethylene fibre developed

Submic has been developed by Nippon Valqua Industries Ltd as a 100% polytetrafluroethylene (PTFE) fibre comprising a series of thin holes, but with typical PTFE properties. End uses for Submic include soundproofing, matrix and dielectric substances and heat insulation. (Short article)

Author: Anon
Source: New Mater. Jpn
Issue: Jan. 2000, p. 2

Current situation and prospects of dialyzer membrane

Asahi Medical KK is a Japanese supplier of sterilised disposable medical goods, including artificial kidneys, blood purifiers and blood transfusion filters. Dialyzer membranes for artificial kidneys are nonwoven products, and their requirement levels have risen dramatically since Asahi Medical launched Japan's first hollow yarn type artificial kidney in 1974. The initial purpose was to extend patients' lives, but advancement of dialyzer technology and treatment has made it possible to raise the quality of everyday life. Essential requirements of the membrane include safety, biological conformity and performance, including removal of low molecular weight protein. To improve biological conformity, new synthetic membranes have been developed, with polysulfon and triacetate developing particularly well since 1995. (8 fig)

Author: Tsuge M
Source: Jpn Nonwovens Rep.
Issue: no. 307, 10 Aug. 1999, pp 8-11 (In Japanese)

Sanitary pads with permeable structure for stuffiness prevention
In Autumn, 1998 Procter & Gamble Far East launched an improved paper baby nappy. The newly developed Clean Skin Sheet on the inside surface keeps feces and urine separate ensuring the baby's skin is protected from irritation. Improved adult incontinence products also focus on a permeable structure for hygiene and skin comfort. P&G has provided a free-call advice for the care of elderly people since 1987 and recently started Home Care Support Programmes. P&G's new sanitary towels are innovative; previously non-stuffiness and leak-free features hardly coexisted, but the problem has been solved by combining a highly permeable back sheet and a second back sheet for comfortable airing and reliable absorption. (3 fig)

Author: Anon
Source: Nonwovens Rev.
Issue: vol. 10, no. 3, 1999, pp 10-11 (In Japanese)

Launch of Fine Series of paper baby nappies
Nepia, Japan, launched their Fine Series of paper baby nappies, FinePa, in Spring 1999. FinePa tape-type have an overall permeable system, and a new soft waterproof material is used for the sides. FinePa pants-type aims at permeability and body-fit as close to underwear as possible. Nepia also launched five types of paper adult nappies and three types of incontinence pads, so users can choose suitable items and combinations according to individual life-style and degree of incontinence. In collaboration with post office counters, Nepia has started postal-delivery sales of these nappies in the Tokyo area, followed by successful operation in Kinki District. (2 fig)

Author: Anon
Source: Nonwovens Rev.
Issue: vol. 10, no. 3, Sept. 1999, p. 14 (In Japanese)

A new nonwoven warming material
A new nonwoven made from finite length hemp cloth (linen) fibres by the action of high pressure water jets placed at specific positions relative to the fibres is reported. The strength of the material is increased by the network formed by the water jets from nozzles arranged at angles of 45-89 degrees relative to the longitudinal direction of the material, distance between nozzles 1.6 cm. Data are for the new material compared with "Thermolite" (DuPont), "Thinsulate," and Sentipon, e.g.: breaking load for the new nonwoven, Thermolite, Thinsulate, and Sentipon 35.7, 12.2, 16.7, and 1.4 Newtons respectively for 50x100 mm strips. The corresponding data for thermal properties per thickness unit are 3.12. 1.66, 0.90, and 0.90 comparative units respectively. (1 tab)

Author: Buzov B A; Mishakov B Yu; Zametta B V
Source: Text. Ind.
Issue: no. 5-6, 1999, p. 36 (In Russian)

Air permeability of jute-based needle-punched nonwoven fabrics

An investigation into the effects of texturisation, blend composition, punch density, depth of needle penetration, jute fibre cut length and web laying technique upon fabric thickness, density and air permeability of needlepunched nonwoven fabrics prepared from jute, chemically texturised jute (TJ) and blends with polypropylene (PP) is documented. In terms of air flow TJ and TJ/PP blended nonwovens had a higher resistance than jute and jute/PP blended fabrics. A positive correlation was observed between air permeability and punch density for jute and jute/PP fabrics, whilst this relationship was negative for TJ and TJ/PP fabrics. Air permeability decreases in jute/PP fabrics and increases in TJ/PP fabrics with increasing PP content. For TJ and jute/PP fabrics increasing jute fibre cut length decreases cut permeability. Random laid jute/PP has higher air permeability than crosslaid jute/PP. (3 fig, 7 tab, 13 ref)

Authors: Sengupta S; Samajpati S; Ganguly P K
Source: Indian J. Fibre Text. Res.
Issue: vol. 24, no. 2, June 1999, pp 103-110

Strong effects: improving the quality of cast PP film by the use of polymer-modified resins

The results of investigations into the advantages of adding hydrocarbon resin to non-oriented cast polypropylene (PP) films are documented. The effects of hydrogenated hydrocarbon resins on the crystallisation behaviour, phase structure and morphology of PP were examined and the nature of polymer modified hydrocarbon resins is detailed. Results indicate that cast PP films containing additives based on polymer modified hydrocarbon resins demonstrate improved properties particularly in terms of modulus of elasticity, barrier effect and optical properties.

Author: Loeber G
Source: Kunstst. Plast Eur.
Issue: vol. 89, no. 12, Dec. 1999, pp 33-34

Ecomark products and qualifications for Ecomark

Ecomark (Japan) is given to products containing recycled polyester fibre. There are currently three classifications: No. 103, cloths and its intermediate products; No. 104, domestic use fabric; No. 105, industrial fibre products (eg. nonwoven, filter, belt, packaging materials). The principal qualification is that Ecomark products should contain more than 50% (w/w) of recycled fibres Other requirements, including six environmental standards and two quality standards, are also summarised. (5 fig, 5 ref)

Author: Takaoka Y
Source: Jpn Nonwovens Rep.
Issue: no. 9, Sept. 1999, pp 46-53 (In Japanese)

Surface monitoring system M71NT from Toshiba Engineering Corp for detecting nonwoven surface defects

Surface monitoring system M71NT (Toshiba Engineering Corp) achieves a real-time surface defect detection on nonwovens, which is difficult to achieve using the conventional close circuit camera system. M71NT is based on the advanced flame digital graphic analysis technology (patented), and most types of defects (eg. unevenness, micro-contamination, streak, and discolouring) can be detected. Detected defects are auto-classified, and responses to them are flexible depending on the degree and type of defects. (5 fig)

Author: Sakashita K
Source: Jpn Nonwovens Rep.
Issue: no. 9, Sept. 1999, pp 28-30 (In Japanese)

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ASTM Methods Development

Anyone who has worked in the area of new test methods and test method developments knows the agony involved in getting approval from a number of individual stake holders. The problem increases when several nations are involved, but it is difficult enough when task is focused on one country or one business segment.

The major U.S. association encumbered with this task is ASTM (American Society for Testing & Materials). This group has now taken the step of exploiting the communication proficiency of the Internet to facilitate and accelerate the approval process.

ASTM has initiated a new version of its ISDF (Interactive Standards Development Forum) technique to further expedite and extend the methods approval process. Forum 2.0 is a selected area on the ASTM website that focuses on specific test methods that are in the approval process. The Forum provides a virtual meeting site for the Task Group assigned a specific test method. The Task Group member can address the topic via HTML and leave comments, suggestions and opinions for the test method Administrator. As an alternate to working on-line, the member can down-load the material, study and make comments on the test text, and then up-load that version and additional comments onto the website for the Administrator's use.

By providing this system, the work of the Task Group can go forward literally on a 7-day/24-hour day basis, conducted from any location that the Task Group member might be.

At the appropriate location on the ASTM website, standards development forms for methods proposal and development, as well as all forms pertaining to methods that are undergoing current processing are available. These sites are classified by the particular committee involved (D-13 for textile subject material). For those who are not yet members of a sub-committee that particularly interests them, there is a procedure for expressing that interest and becoming an active member of the sub-committee. (Dan Schultz, American Society for Testing & Materials, 100 Barr Harbor Drive, W. Conshohocken, PA 19428; 610-832-9500; Fax: 610-832-9555; www.astm.org).

ATMI E-Newsletter On Standards

The American Textile Manufacturers Institute (ATMI) recently established a monthly electronic newsletter that will cover issues relating to standards associated with the textile industry. This information will be concerned with textile consumer products, machinery, health and safety, the environment and electronic commerce, plus the latest activities in the international standards arena.

This new offering is entitled ASTM Strategic Standards News. The newsletter will be available in the electronic format only and will available free to those who have an interest in this subject.

In addition to the monthly electronic newsletter, subscribers will receive individual notices via E-mail about new articles, upcoming standards-related events and other services. Subscribers can also have easy access to information about domestic efforts to harmonize U.S. textile standards with those of NAFTA partners, as well as the status of technical standards for textile machinery and workplace issues.

ATMI is the national trade association for the U.S. textile industry and serves as the U.S. administrator for the ISO (International Organization for Standardization) Technical Committee TC38 on textiles and TC72 on textile machinery.

To subscribe to ASTM's Strategic Standards News, a simple registration form can be completed at the ASTM web site (www.atmi.org/standards/subscribeto.htm.) Alternately, a subscription request can be E-mailed to standardsnews@atmi.org

Pulps and Pulping
Research Collaboration
Driven by current activities in the current globalization of the Pulp and Paper Industry, a collaboration in the pulp research area has been accomplished. Two major organizations carrying out research on pulps and pulping have recently agreed to combine their efforts in order to facilitate the securing of research and contract work in these areas. The Finnish Pulp and Paper Research Institute (KCL) and the Swedish Pulp and Paper Institute (STFI) have signed an agreement for research collaborations in the areas of chemical pulp and mechanical pulp research.

Both of these organizations are world renown for their broad studies in the area of pulp and paper technology. The new research collaboration will focus in the areas of pulping research, providing a single research center that combines some of finest facilities as well as an impressive talent pool for research in this area.

New Chairman for INDA's
Healthcare and Wipes Committees
Two prominent committees within INDA have recently obtained new chairmen.

The Healthcare Committee of INDA will be chaired by Jon Behm of Allegiance Healthcare. Mr. Behm is currently the Director of Research and Development at Allegiance Healthcare, where he has spent the past 15 years of his career. His experience includes engineering, production management, marketing and R&D involving packaging, custom procedure packs, disposable drapes, packs and gowns. Mr. Behm has a Bachelor's Degree in mechanical engineering from Brandley University and an MBA in Marketing from DePaul University.

The new chairman of the INDA Wipes Committee is Ralph Solarski, currently the Manufacturing Market Segment Manager with Kimberly-Clark; in this assignment he has responsibilities for directing marketing activities to the industrial/marketing workplace for the Away From Home Sector's industrial wipers, towel and tissue products and skin care products. Prior to this position, Mr. Solarski was the Director of Marketing for National Account at the Sweetheart Cup Company. He has a BA degree in Finance from the University of Notre Dame and an MBA from The University of North Carolina at Chapel Hill.

International Nonwovens Directory

The 15th edition of INDA's International Nonwovens Directory has been released to the industry worldwide. The 540-page volume has been published and edited by INDA, Association of the Nonwoven Fabrics Industry, and co-edited by EDANA, European Nonwovens & Disposable Association. In addition to these principal participants, the cooperation of several other trade associations went into production of this premier directory of the international industry:

- All Nippon Nonwovens Association (ANNA)
- Brazilian Nonwoven Fabric Industries Association (ABINT)
- China Nonwovens and Industrial Textiles Association (CNITA)
- China Nonwovens Technical Association (CNTA)
- Korea Nonwovens Industry Cooperative
- Taiwan Nonwoven Fabrics Industry Association (TNFIA)

Use of the Directory is facilitated by an extensive index of products and services. This categorizes the entire volume by the following classification:

- Material Suppliers
- Machinery and Equipment Manufact-urers and Suppliers
- Nonwoven Roll Goods Suppliers
- Finished Product Manufacturers
- Nonwoven Roll Goods Producers, Suppliers by Types of Structures
- Commission Services: Fabric Finishers and Product Converters and Fabricators
- Third Party Research and Development, Testing, Teaching
- Consultants
- Sales Agents, Distributors, Importers, Exporters
- Government Agencies, Journals and Associations

The alphabetical listing of companies, which comprises the heart of the Directory, provides information on the company locations, personnel, communication means and details on the products and services provided.

Searching of the company listings by geographical location is also possible. This is facilitated by a listing of all of the companies according to the countries in which they are located. A total of 58 individual countries is provided in this listing.

INDA has also announced that an on-line version of the Directory will be available a little later this year.

Copies of the 15th International Nonwovens Directory can be obtained from INDA, Cindy Garcia, 919-233-1210, ext. 111; or EDANA, European Disposables and Nonwovens Association, 157 Avenue Eugene Plasky, 1030 Brussels, Belgium; Tel.: 32+2/734-9310; Fax: 32+2/733-3518; or from the office of any of the cooperating trade associations.

New ISO Standards
The International Standards Organization is responsible for establishing and obtaining approval on those standards that have been agreed upon on an international basis. At the present time, over 100 countries worldwide participate in the development and approval, and adhere to these standards.

The Technical Committee within ISO that is responsible for standards on textiles issues, including woven, knit and nonwoven, is TC38. This committee recently issued three new methods of interest to the entire industry:

- ISO 13431:1999 - Geotextiles and geotextile-related products: Determin-ation of tensile creep and creep rupture behavior.
- ISO 13938-1:1999 - Textiles-Bursting properties of fabrics, Part 1: Hydraulic method for determination of bursting strength and bursting distension.
- ISO 13938-2:1999 - Textiles-Bursting properties of fabrics, Part 2: Pneumatic method for determination of bursting strength and bursting distension.

Copies of these new standard methods can be obtained directly from ISO Central Secretariat, 1 rue de Varembe, 1211 Geneve 20, Switzerland; or from the local ISO representative. In the U.S.: American National Standards Institute (ANSI), Customer Service Department, 13th Floor, 11 West 42nd Street, New York, NY 10036; 888-267-4783; Fax: 212-302-1286.

New Secretary General at EDANA
With the retirement of Guy Massenaux as Secretary General of EDANA, the Board of Governors of EDANA recently appointed Gerard Nauwelaerts to this position. The Secretary General is the top professional position within the association.

Mr. Nauwelaerts is a Belgian national, who is fluent in English and French, as well as his mother tongue of Dutch. He is 54 years old and he holds a Master's Degree in EU Law and Political Institutions. He has worked in a number of legal positions, including the position of Legal and European Affairs Counsel for FEBIAC, the Belgian Automobile Manufacturers Association.

Until early 1999, Mr. Nauwelaerts was Secretary General of EACEM, the European Association of Consumer Electronics Manufacturers.

INJ is pleased to extend a sincere thanks to Mr. Massenaux for his years of effective service, and a heartfelt wish for a happy retirement. At the same time, a warm welcome and congratulations is extended to Mr. Nauwelaerts.

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For a report on the Third Nonwovens Symposium 2000 Cotton Beltwide Conference, click here.

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NONWOVENS CALENDAR 2000

Apr. 2-6. ***47th Annual AORN Congress.*** Ernest N. Morial Convention Center, New Orleans, LA. Janet Paulson, Public Relations Project Manager, Association of Operating Room Nurses, 2170 South Parker Road, Suite 300, Denver, CO 80231; 303-755-6304, ext. 235; Fax: 303-338-4838; jpaulson@aorn.org

Apr. 3-6. ***Applications of Image Analysis to Fibrous Structures.*** College of Textiles, North Carolina State University, Raleigh, NC. J. Bullock, NC State: NCRC, Box 8301, 2401 Research Dr., Raleigh, NC 27695-8301; jbullock@tx.ncsu.edu

Apr. 3-7. ***Eighth World Filtration Congress.*** The Brighton Centre, Brighton, England. The Secretariat, World Filtration Congress 8, 48 Springfield Road, Horsham RH 12 2PD West Sussex, England. Tel: +44 (0) 1403-265005; Fax: +44 (0) 1403-257594. filtech.exhibitions@btinterent.com

Apr. 4-6. ***Annual Private Label Expo and Contract Packaging Expo***. Las Vegas, NV. Bentley International Group, 3690 S. Eastern Ave., Suite 201, Las Vegas, NV; 702-893-9090; Fax: 702-893-9293.

Apr. 10-12. ***Laboratory Automation in Process R&D.*** Boston, MA. Scientific Update, Wyvern Cottage, High St., Mayfield, East Sussex T20 6AE, England; 44-1485-873062; Fax: 44-1435-872734; sciup@scientificupdate.co.uk

Apr. 16-17. ***Annual Meeting - The Inter-Society Color Council (ISCC).*** Charlotte, NC. ISCC office; Tel: 703-318-0263; iscc@compuserve.com

Apr. 16-19. ***The 80th World Conference of The Textile Institute.*** Manchester, UK. The Textile Institute International, 4th Floor, St. James' Building, Oxford Street, Manchester M1 6FQ, UK; +44-161-237-1189; Fax: +44-161-236-1991; www.texi.org

Apr. 17-19. ***TAPPI/IPST Fiber and Paper Physics Short Course.*** Crowne Plaza Resort, Hilton Head Island, SC. TAPPI, Charles Bohanan; 770-209-7276; cbohanan@tappi.org.

Apr. 17-20. ***Nonwovens Workshop Principles and Practices.*** North Carolina State University, Raleigh, NC. Janey Bullock, NCRC, P.O. Box 8301 NCSU, Raleigh, NC 27695; 919-515-6551; jbullock@tx.ncsu.edu

Apr. 26-27. ***Fundamentals of Finishes for Fibers.*** College of Textiles, North Carolina State University, Raleigh, NC. J. Bullock, NC State University: NCRC, Box 8301, 2401 Research Dr., Raleigh, NC 27695; jbullock@tx.ncsu.edu

Apr. 26-27. ***Institute of Textile Technology Technical Advisory Committee and Board Meeting.*** Charlottesville, VA. Institute of Textile Technology, 2551 Ivy Road, Charlottesville, VA; 804-296-5511; Fax: 804-296-2957; www.itt.edu

Apr. 26-28. ***International Conference on Safety and Protective Fabrics.*** Hyatt Regency Crystal City, Arlington, VA. Doris Runa, Industrial Fabrics Association International, 1801 County Rd BW. Roseville, MN 55113; 800-225-4324; www.ifai.com.

Apr. 26-28. ***INDA Needlepunch 2000 International Conference.*** Hyatt Regency Greenville, Greenville, SC. INDA, Association of the Nonwoven Fabrics Industry, P.O. Box 1288, Cary, NC 27512; 919-233-1210; Fax: 919-233-1282; www.inda.org

May 2000

May 1-2. ***The 5th Annual Conference on Recycling of Fibrous Textile and Carpet Waste.*** Northwest Georgia Trade and Conference Center, Dalton, GA. Continuing Education Dept., Georgia Tech, Atlanta, GA 30332; 404-385-3502; www.conted.gatech.edu.

May 17-19. ***ANEX 2000 Asia Nonwovens Exhibition/Conference.*** Intex Osaka, Osaka, Japan. E. J. Krause, John Gallagher. 301-493-5500; gallagher@ejkrause.com

May 23-24. ***World of Private Label Trade Show.*** RAI Exhibition Center, Amsterdam, The Netherlands. PLMA International Council, World Trade Center, Stawinsky-Iaan 705, 1077XX Amsterdam, The Netherlands; 31-20-575-3032; Fax: 31-20-575-3093.

May 24-26. ***CINTE Tech Textil. The China International Nonwovens, Techtextiles & Machinery Exhibition and Conference.*** China International Exhibition Centre, Beijing, China. Messe Frankfurt (HK) Ltd., 1808 China Resources Building, 26 Harbour Road, Wanchai, Hong Kong, China. Shirley Yan, Tel: 852-2238-9932; Janet Lai, 852-2238-9930

June 2000

June 7-8. ***EDANA 2000 Inter-national Nonwovens Symposium.*** Prague, the Czech Republic. For more information contact: EDANA, Philip Preest, Marketing Director; 157, avenue Eugene Plasky, Bte 4, 1040 Brussels, Belgium; 011+32+2/734-9310; Fax: +32-2/733-3518; edana@euronet.be

June 19-21. ***The TRI/Princeton Workshop "Characterization of Porous Materials: from Angstroms to Millimeters."*** Hyatt Regency Princeton, Princeton, NJ. Nicole Pozsonyi, TRI/Princeton, 601 Prospect Avenue, P.O. Box 625, Princeton, NJ 08542. 609-430-4806

June 25-28. ***TAPPI Hot Melt Symposium.*** Sheraton Bal Harbour, Bal Harbour, FL. TAPPI, Charles Bohanan; 770-209-7276; cbohanan@tappi.org.

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INJ DEPARTMENTS

An Analysis of Fabric 'Hand' and 'Feel'

By R.W. Dent, Albany International Research Co., Mansfield, MA

Abstract
A comprehensive analysis of fabric "hand" or "feel" can be obtained by a full evaluation using the "Kawabata" or "Fast" systems. However, for quick, cheap ranking of only the main factors of hand, the ring and slot methods can be used. In a ring test the fabric is pulled through a ring and the maximum force is taken as a measure of the fabric hand. In the slot test, the fabric is pushed through a slot and the complete force deflection curve is measured. An analysis of the mechanics of this test is given in this paper and shows that (because of the simpler test configuration) the initial slope gives a measure of the fabric flexural rigidity or stiffness while the ratio of the maximum load to the initial slope gives a measure of the fabric friction or smoothness. Thus in a single test we can measure "hand", "stiffness" and "smoothness" directly. By parallel measurements of the fabric shear and compression, we can assess the fabric "drape" and "softness".

Introduction
The hand, handle or feel of a fabric plays an important role in the decision by a customer to purchase one or another fabric. The fabric producers and garment manufacturers would love to have a simple, cheap objective test to duplicate this subjective customer assessment.

Often they rely on a panel of experts whose subjective assessment is supposed to reflect that of the customers. Ultimately the goal is to replace such a judgment by one or two objective tests which will give essentially the same information and ranking as the panel subjective judgment.

There are two main approaches to developing such an objective method. These can be called (I) the Kawabata method and (II) "hand" testers. These are discussed next.

Experimental Approaches
The Kawabata Method
This method has been summarized by Kawabata, Niwa and Wang [1], Bishop [2], and Matsuo [3]. In this method the assumption is made that the subjective judgment of the hand of a fabric is a composite synthesis of many of the physical properties of the fabric, which the brain judges automatically. It is assumed that the relevant physical properties are the tensile, shear, flexural, compressive and surface properties as well as weight and thickness. These are represented by 17 separate variables or parameters in the Kawabata method, which are measured independently.

The technique is to establish a regression equation between these 17 variables obtained for a large number of fabrics and the subjective ratings obtained from the consensus of a large panel of experts for the same fabrics. With 17 independent variables the regression will be almost perfect and the statistical process needs to be done very carefully so as not to obtain a meaningless regression.

This method is the basis of the Kawabata system, which uses the 5 Kawabata (KES) testers to obtain the 17 values for each fabric. A recent cheaper system from CSIRO is the "Fast" system that uses only three testers and 15 variables.

Both of these methods require the purchase of several pieces of expensive equipment as well as the significant cost of testing each fabric along with some rather delicate expert statistical data weighting and analysis. This is certainly the best method for basic research.

"Hand" Testers

For production and routine research screening, however, it is desirable to have an alternative simple, cheap, easy test giving only a few main values of assessment rather than seventeen! This requires that there is a prior agreement as to which of the main fabric properties are those which are mainly responsible for fabric hand. Essentially we want to replace the 17 Kawabata parameters by only the two or three main principal ones and eliminate the multifactor statistical correlation methods, if possible.

Peirce [4] was the first to attempt to do this scientifically and concluded that hand and feel depended on stiffness, softness and smoothness and in order to measure the "stiffness" or "flexural rigidity" of a fabric he developed the bending length test. The roles of "stiffness", "smoothness" and thickness or weight in determining hand were confirmed by Haworth [5] [6] for suitings, dresses and lingerie fabrics by the use of multi Factor Analysis. "Smoothness" is presumably determined by the fabric surface roughness and coefficient of friction so that the properties to test in a "hand" tester are some combination of the fabric stiffness or rigidity and its surface frictional and topological characteristics. These can be measured by ring or slot tests.

The Ring Test

Many ring testers have been developed and some are currently available on the market. Some of these are the Drape Resistance tester, the Fabricometer or tactometer and the Hand Feel Comparator discussed in the INDA Softness-Hand Research Study [7], the Dexter Ring and Rod Softness Tester [8], the NASA Handle Tester [9], and the U. Maryland Tester [10, 11]. These have been used to measure paper and nonwovens as well as knits and woven fabrics. Some are stand-alone testers while others are Instron attachments. They are claimed variously to measure hand, feel and drapeability and also "softness". However, Elder [12] shows that softness is due to compression only, so that a softness tester is not necessarily a Hand and Feel or Drape tester.

The ring method is simply to pull a fabric through a smooth ring and measure the maximum force. Clearly this force depends on the fabric stiffness and surface properties (smoothness and friction) as well as the fabric thickness and its shearability. Values are found to correlate extremely well with panel subjective rankings and have been used as an empirical test for centuries [10].

An analysis of the mechanics of this 3D Extraction method has been given by Alley & McHatton [9] and subsequently improved by Alley [13] and more recently by Pan & Yen [14].

The Slot Test

An alternative to the ring test is one where the fabric is pulled or pushed through a slot rather than a ring. The slot or gap can be adjusted to any desired width between two plates [15, 16, 17]. One such tester is the Handle-o-meter [18] which was described in a Tappi proposed standard for "softness" [19].

This tester operates with a blade on an arm which pushes the fabric into the slot. Because of the arm, this tester can be operated on-line, at least in principle. A similar test is the Handmeter which is a simple attachment for the Instron [20] .

The use of a slot rather than a ring is an important difference. It means that one can measure stiffness and friction in a clear unambiguous manner and these are assumed to be the main components (with thickness and weight) of hand and feel. The ring test involves these along with shear and hence is perhaps a better indicator of "drape" rather than of "hand"! Of course, an extra, separate shear test could be used to complement the hand data from the Handmeter to give the complete information about the drape characteristics of a fabric.

The important thing is that the mechanics of the 2D slot are much easier to analyze than for the 3D ring. This analysis is given next.

Theoretical Analysis of the Slot Test

The basic action of the test is simply to pull (or push) a fabric through the slot at a constant rate, while measuring the resultant force on the center point of the fabric as indicated in *Figure 1*. The analysis of the mechanics is similar to that considered in classical Elasticity theory [21] for the large deflections of a plate (or Elastica) but with extra deflecting forces. All the forces and moments are shown in *Figure 2*. The fabric weight and thickness are initially considered to be negligible.

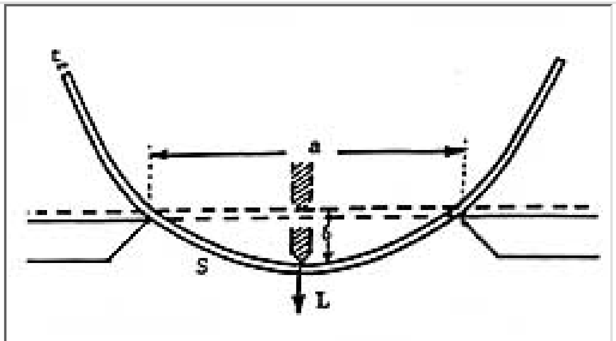

Figure 1
THE TEST ARRANGEMENT

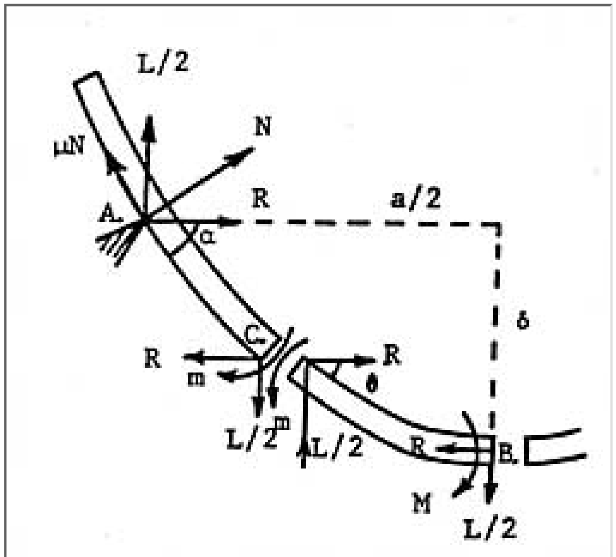

Figure 2
FORCES INVOLVED IN THE FABRIC DEFORMATION

Balancing forces and moments gives the normal reaction force as

$$N = \frac{L}{2}\cos\lambda\,\sec(\lambda - \alpha)$$

and the horizontal force is

$$R = \frac{-L}{2}\tan(\lambda - \alpha)$$

Balancing moments and differentiating gives

$$-EI\frac{d^2\theta}{ds^2} = \frac{L}{2}\left[\cos\theta - \tan(\lambda - \alpha)\sin\theta\right]$$

Integrating and using the boundary condition

$$\frac{d\theta}{ds} = 0 \; at \; \theta = \alpha$$

gives

$$\frac{d\theta}{ds} = -\left\{\frac{L}{EI}\sec(\lambda - \alpha)\left[\sin\lambda - \sin(\lambda + \theta - \alpha)\right]\right\}^{1/2}$$

when taking the negative root.

As $\theta = 0$ at the point *B* we can find $\left(\frac{d\theta}{ds}\right)_B$ and taking moments about *A* gives

$$EI\left(\frac{d\theta}{ds}\right)_B = \frac{L}{2}\left[\frac{a}{2} - \delta\tan(\lambda - \alpha)\right]$$

and hence

$$\frac{\delta}{a} = \frac{1}{2}\cot(\lambda - \alpha)\left[1 - \left\{\frac{16EI}{La^2}\sec(\lambda - \alpha)\left[\sin\lambda - \sin(\lambda - \alpha)\right]\right\}^{1/2}\right] \quad \text{-(1)}$$

which is the expression for the deflection δ of the center point of the beam (or fabric) as a function of α under a load *L* for a gap (or slot) width a and a friction angle λ, obtained from the coefficient of friction μ by μ = tan λ. α is the fabric inclination angle at the point of contact A while EI is the flexural rigidity per unit width of the fabric. We can obtain an expression for the gap by integrating

$$\int_0^{a/2} dx = \int_\alpha^0 \frac{\cos\theta}{d\theta/ds} d\theta$$

or

$$\frac{a}{2} = \sqrt{\frac{EI}{L}\cos(\lambda-\alpha)} \int_0^\alpha \frac{\cos\theta d\theta}{\sqrt{\sin\lambda - \sin(\lambda+\theta-\alpha)}}$$

After some manipulation, this leads to

$$\frac{La^2}{8EI}\sec(\lambda-\alpha) = \left[2p\cos(\lambda-\alpha)\cos\phi - \{F(\psi) - G(\psi)\}\sin(\lambda-\alpha)\right]^2 \quad - (2)$$

where $p = \sin\beta$ and $\beta = \frac{\pi}{4} + \frac{\lambda}{2}$

$\sin\phi = \frac{1}{p}\sin(\beta - \frac{\alpha}{2})$ and $\psi = \frac{\pi}{2} - \phi$

while $G(\psi) = \int_0^\psi \frac{dm}{\sqrt{1-p^2\cos^2 m}}$ and $F(\psi) = 2\int_0^\psi \sqrt{1-p^2\cos^2 m}\,.dm$

are incomplete elliptic integrals of the first and second kinds, respectively, with modulus *p*.

This last equation (2) has been given by Frisch-Fay [22] and gives the load *L* as a function of the inclination angle *a* . Unfortunately *a* is unknown and difficult to measure in our test, so that eq. (2) is not useful as it stands. However, as eq. (1) gives the relationship between the *L*, *a* and the deflection δ we can eliminate *a* and obtain the load-deflection relation directly relating *L* to δ - or, alternately - we can select *a* , calculate *L* from eq. (2) and δ from eq. (1), using *a* as a parameter, to obtain *L* as a function of δ implicity.

Using eqs. (1) and (2), La^2/EI is plotted against δ/a in *Figure 3* as a series of curves with only one variable, the surface friction μ . Interestingly the normalized initial slope is seen to be independent of the friction μ , but the peak load L_m (which has been taken as a measure of hand [20, 23]) is seen to be affected by the friction as are all of the subsequent decreasing loads. Calculating *a* shows that the maximum occurs when $\alpha \approx 45°$ and the loads are small by the time $\alpha \rightarrow 90°$. Often, in ring and slot tests the maximum load has been called the "softness"[11][19]. However, as it has been shown that "softness" is related more to compression[12], which is absent in the slot test, then we must take L_m in the slot test as a measure of "hand" or "feel" rather than "softness". This conforms to the terminology of others[10].

In passing, we can note that the corresponding sample deflected length *S* is given by

$$S/a = \left[\frac{2EI}{La^2}\cos(\lambda-\alpha)\right]^{\frac{1}{2}} G(\psi) \quad - (3)$$

We will not use this result here as *S* is difficult to measure.

Curve Parameters
Flexural Rigidity
Figure 3 suggests that the normalized initial slope S_o is constant and we can confirm this and obtain this value by

solving $$S_o = \left(\frac{dL}{d\delta}\right)_{\alpha \to o} = \frac{\left(dL/d\alpha\right)_{\alpha \to o}}{\left(d\delta/d\alpha\right)_{\alpha \to o}}$$

These last two terms are obtained directly from the limits of eqs. (2) and (1) as given by eqs. A4 and A5 in the Appendix. The results are

$$\frac{a^2}{8EI}\left(\frac{dL}{d\alpha}\right)_{\alpha \to o} = \frac{Y}{\alpha} = 2\left(1 + \frac{5}{6}\alpha \tan\lambda\right)$$

and $$\frac{2}{a}\left(\frac{d\delta}{d\alpha}\right)_{\alpha \to o} = \frac{X}{\alpha} = \frac{2}{3}\left(1 + \frac{1}{30}\alpha \tan\lambda\right)$$

for general λ, ignoring terms in a^2 and above.

Thus we see that

$$\frac{a^3}{16EI}S_o = \frac{3\left(1 + \frac{5}{6}\alpha \tan\lambda\right)}{\left(1 + \frac{1}{30}\alpha \tan\lambda\right)} = 3\left(1 + \frac{4}{5}\alpha \tan\lambda\right)$$

or $$S_o = \frac{48EI}{a^3}\left(1 + \frac{4}{5}\alpha \tan\lambda\right)$$

The limiting value when $a \to$ o agrees correctly with the classical result from small strain theory [21].

$$S_o = 48EI/a^3 \quad \text{-(4)}$$

Thus we can obtain the flexural rigidity per unit width of the fabric *EI* directly from the measured initial slope S_o and the slot width *a*. If we also measure the fabric thickness *t*, we can calculate the moment $I = \frac{t^3}{12}$ and from the rigidity *EI* we can obtain the bending modulus *E* and even an estimate of the bending length *c* from [4] $EI = Wc^3$ where W is the weight/unit area.

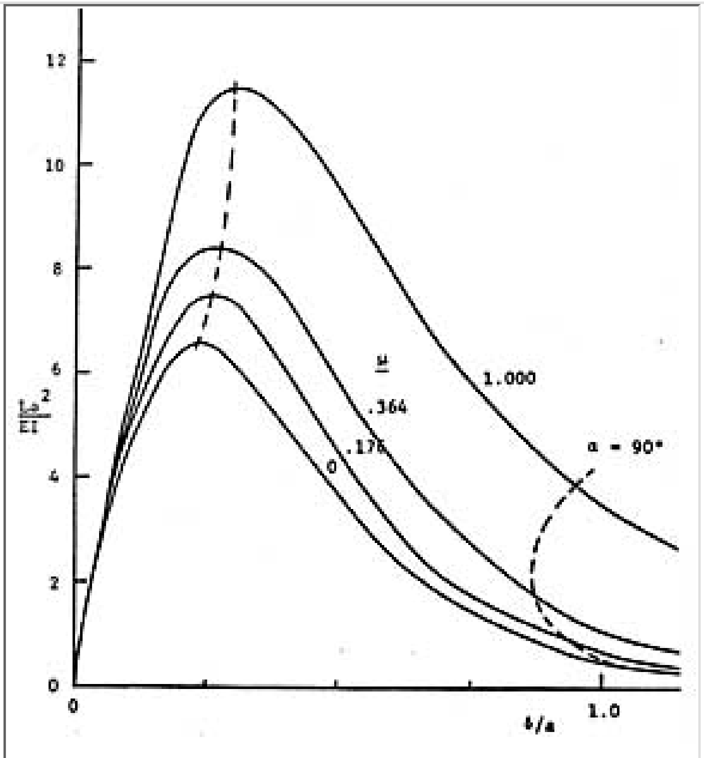

Figure 3
THE LOAD-DEFLECTION RELATIONSHIP

Also we note that $\left(\frac{dL}{d\alpha}\right)_{\alpha\to 0} = \frac{16EI}{a^2}$ and $\left(\frac{dS}{d\alpha}\right)_{\alpha\to 0} = \frac{a}{3}$.

Coefficient of Friction
Examination of *Figure 3* shows that, whereas the initial slope S_o is independent of the friction μ , the maximum L_m of the normalized master load-deflection plot is highly dependent on μ (or tan λ). Differentiation of eq. (2) for the maximum in the curve may be difficult but an approximate graphical relationship may be practically useful.

By plotting the curves of λ for every 5º from 0 to 45º (0<μ <1) we can obtain the general relationship between the maximum Y_m and μ . We find that approximately

$$Y_m = \frac{L_m a^2}{8EI} = 0.835 + 0.59\mu \quad - (5)$$

Hence, as *EI* has been obtained from the initial slope S_o by using eq. (4), μ can be obtained directly from the measurement of the peak force or load L_m of the experimental curve by using eq. (5). The only other value needed is that of the known slot width *a*.

Further examination of *Figure 3* shows that the maximum occurs when $\frac{\delta}{a} \approx 0.25$. This is a good check that the measurements are valid. There may be some combinations of *EI*, *a* and *t* which are inappropriate. This is discussed later.

Discussion
Maximum Load and Hand
When a fabric is pulled or pushed through a straight slot, the maximum load L_m is taken as a measure of fabric "hand" or "feel".[19, 23, 10, 24] rather than "softness" [20].

The analysis given in this paper shows that the initial slope of the load-deflection curve from the slot test gives the fabric stiffness or flexural rigidity *EI*, while the ratio of maximum load L_m to initial slope S_o, from eqs. (4) and (5) gives the friction from

$$\frac{L_m}{aS_o} = 0.14 + 0.10\mu$$

and allows μ to be calculated for a particular slot width *a*. Thus this test gives us "hand", "stiffness" and "friction" directly. Certainly stiffness *EI* and effective surface friction μ (allowing for roughness) are two of the main factors in "hand". Whether this test always combines them in the appropriate correct proportions as sensed when judging the hand of a fabric, remains to be universally established. However, several correlations with groups of people appear to agree well, at least in groups of similar fabrics as given later. Certainly to at least a limited degree, we can "measure the immeasurable".[25] A couple of such ranking evaluations are described later.

Slot Gap Width
Equations (4) and (5) suggest that knowledge of the slot width a is the only extra factor needed besides the load-deflection curve. However, the analysis given here ignores the fabric weight/unit area *W* and its thickness *t*. Thus if a particular fabric has a low rigidity and is heavy, it will require to be tested with a narrow slot width! The slot width however must be greater than twice the fabric thickness plus the width of the deflector. Hence, the deflector should be relatively narrow and radiused as also should the slot contacting edges.

It should be noted that the measured friction is the value between these edges and the fabric so that the edges should be carefully selected. If necessary, extra fabric could be taped to these surfaces to give a fabric to fabric friction measure.

Also when the fabric is much stiffer in one direction (warp or wale, etc.) than the other then different gaps may be required for MD and TD tests. Secondly if the fabric has a finish on one surface or has a two-sided structure one often detects significantly different top to bottom frictional properties due to physical or topological causes. When done properly, the test is extremely sensitive to such differences. An extension of the theory to deal with fabric weight/unit area W and thickness t might allow appropriate corrections from a single set of test conditions. Until such a time, caution should be used when comparing different fabric types and different constructions. Also different types may need quite different test settings of gap width so that knits should generally not be tested like nonwovens, etc.

Some Results

One series of acrylic double knits were ranked 1 to 6 (soft to harsh) by a panel of judges and tested on a handmeter with the following results shown in *Table 1*.

It is seen that the fabric ranking reflects mainly thickness and stiffness differences - as the friction or smoothness values L_m/S_o are almost constant. Fabric 3 is the only outlier from a perfect correlation of "hand" L_m with the Subjective Rank order.

Table 1
DOUBLE KNIT RESULTS

Subjective Rank	**1**	**2**	**3**	**4**	**5**	**6**
S_o	23.7	26.3	24.1	31.5	32.2	34.1
L_m/S_o	.47	.48	.48	.47	.47	.49
L_m	11.0	12.2	11.3	14.5	15.1	16.4
E	1.8	1.7	1.7	2.3	2.1	2.1

A second woven fabric series with a common warp but different fillings were rated in *Table 2* by a panel of experts from 1 to 5 (most desirable to least desirable).

Here the hand or maximum load values L_m agreed perfectly with the subjective panel ranking. In this case desirable fabrics (for this end use) were those which were less stiff (S_o) but had larger "friction" values (L_m/S_o).

Table 2
WOVEN FABRIC RESULTS

Subjective Rank	**1**	**2**	**3**	**4**	**5**
S_o	12.4	22.2	41.5	50.2	66.6
$L_m/_o$	.296	.304	.291	.295	.281
L_m	3.7	6.7	11.9	14.7	18.3
E	17.5	38.1	57.0	57.6	77.9

Next, two washed nonwovens were tested, one being judged "soft" and one "harsh." The relevant values are given in *Table 3*.

Here we see that the "harsh" fabric was actually less stiff but had a much larger friction value L_m/S_o than the "soft" fabric. In this case, the friction or roughness property dominated.

Conclusions

An analysis of the mechanical action of the slot type of "hand" test is given. This allows one to directly obtain the hand, stiffness and smoothness properties of a fabric from a single test using an Instron attachment. Some examples are given where the results obtained correlate well with panel rankings of the same fabrics.

Table 3
NONWOVEN RESULTS

	Soft	**Harsh**
S_o	63	44
L_m/S_o	.270	.337
L_m	17	15
E	2.0	0.5

By also making a shear measurement of the fabric, we can obtain the "drape" characteristics of the fabric as well as its "hand" or "feel". A further measurement of its compression would give a measure of fabric "softness". These are different properties which may be related. The ring or extraction tester may give a better direct measure of "drape" characteristics. The slot and ring methods described here are suitable for rapid, development evaluation, but for research needs one should perhaps use the comprehensive Kawabata or Fast methods.

AN ANALYSIS OF FABRIC "HAND" AND "FEEL" APPENDIX

Limiting Values for Small a

From eq. (2) we see that $\frac{La^2}{8EI} = Y$ can be written as an expansion in *a* , for general friction tan λ , noting that

$$\cos\phi^1 = (\alpha\cot\beta)^{1/2}\left\{1 + C\alpha + F\alpha^2\right\}$$ - (A1)

and

$$F(\psi) - G(\psi) = \frac{-\sin\lambda}{\cos\beta}(\alpha\cot\beta)^{1/2}(1 + D\alpha + E\alpha^2)$$ - (A2)

while $p = \sin\beta$ and $\cos\lambda = 2\sin\beta\cos\beta$.

Also

$$\cos(\lambda - \alpha) = \cos\lambda(1 + \alpha\tan\lambda - \frac{\alpha^2}{2})$$

and

$$\sin(\lambda - \alpha) = \sin\lambda(1 - \alpha\cot\lambda - \frac{\alpha^2}{2})$$

The value of $\cos\phi^1$ is obtained from

$$\sin\phi^1 = \frac{\sin(\beta - \frac{\alpha}{2})}{\sin\beta} = 1 - \frac{\alpha}{2}\cot\beta - \frac{\alpha^2}{8} + \frac{\alpha^3}{48}\cot\beta$$

and

$$\cos\phi^1 = \left[1 - \sin^2\phi^1\right]^{1/2}$$

This gives

$$C = \frac{1}{4}\tan\lambda$$ and $$F = -\frac{\tan^2\lambda}{32} - \frac{1}{12}$$

The value of $F\Psi$) is obtained from the Maclaurin series expansion of $F\Psi$)

$$F(\psi) = F(0) + \psi F^{I}(0) + \frac{\psi^2}{2}F^{II}(0) + \ \ldots$$

where $F^{I}(\psi), F^{II}(\psi), etc.$ are the first, second, etc. derivatives of *F*. It can be shown that

$$F^{I}(\psi) = 2\sqrt{1 - p^2\cos^2\psi},\quad F^{II}(\psi) = \frac{p^2\sin 2\psi}{\sqrt{1-p^2\cos^2\psi}}$$ etc., up to

$$F^{V}(\psi) = -\frac{8p^2\cos 2\psi}{\sqrt{1-p^2\cos^2\psi}} + \frac{2p^4(\sin^2 2\psi - 3\cos 4\psi)}{(1-p^2\cos^2\psi)^{3/2}} + \frac{9p^6\sin 2\psi\sin 4\psi}{2(1-p^2\cos^2\psi)^{5/2}} - \frac{15p^8\sin^4 2\psi}{8(1-p^2\cos^2\psi)^{7/2}}$$

and the same for $G(\Psi)$ up to $G^{V}(\Psi)$.

It follows that $$F^{I}(0) = 2\sqrt{1-p^2},\quad F^{III}(0) = 2p^2/\sqrt{1-p^2}$$ and $$F^{V}(0) = \frac{2p^2(p^2-4)}{(1-p^2)^{3/2}}$$

while all even derivatives are zero.

Similarly, $$G^{I}(0) = 1/\sqrt{1-p^2},\quad G^{III}(0) = \frac{-p^2}{(1-p^2)^{3/2}}\ and\ G^{V}(0) = \frac{p^2(4+5p^2)}{(1-p^2)^{5/2}}$$

Ultimately, this gives

$$F(\psi) - G(\psi) = \frac{\psi(1-2p^2)}{\sqrt{1-p^2}} + \frac{\psi^3}{6}p^2\frac{(3-2p^2)}{(1-p^2)^{3/2}} - \frac{\psi^5 p^2(12-5p^2+2p^4)}{120(1-p^2)^{5/2}} + \ldots$$ -(A3)

while Ψ is obtained from

$$\psi = \cos^{-1}(\sin\lambda)$$

or

$$\psi^2 = 2(1-\sin\lambda) + \frac{1}{3}(1-\sin\lambda)^2 + \frac{4}{45}(1-\sin\lambda)^3 + \ldots$$

This leads to

$$\psi = (\alpha\cot\beta)^{1/2}(1 + A\alpha + B\alpha^2)$$

where $$A = \frac{\tan\beta}{8} + \frac{\cot\beta}{24}$$ and

$$B = \frac{1}{180}\cot^2\beta - \frac{1}{2}A^2.$$

In eq. (A3) we note that

$\sqrt{1-p^2} = \cos\beta$ and $\sin\lambda = \sin^2\beta - \cos^2\beta$ so that $1-2p^2 = -\sin\lambda$.

Expressed in terms of a rather than Ψ , this gives eq. (A2) where

$D = \frac{1}{4}\tan\lambda - \frac{1}{3\sin\lambda\cos\lambda}$ and $E = \frac{3}{160}\tan^2\lambda - \frac{1}{30}$

after some manipulation.

Substituting A1 and A2 into eq. (2) gives

$$Y = 2\alpha\frac{\cos(\lambda-\alpha)}{\cos\lambda}\left[1+\alpha(C\cos^2\lambda + D\sin^2\lambda) - \left\{\frac{1}{2} + (D-C)\sin\lambda\cos\lambda - (F\cos^2\lambda + E\sin^2\lambda)\right\}\alpha^2\right]^2$$ or

$Y = 2\alpha(1 + N\alpha + M\alpha^2)$ - (A4)

where $N = \frac{5}{6}\tan\lambda$ and $M = -(1 + \frac{11}{90}\tan^2\lambda)$

Using eq. A4 and substituting into eq. (1) gives

$$X = \frac{2\delta}{a} = \cot(\lambda-\alpha)\left\{1 - \left[\frac{2}{Y}\frac{\{\sin\lambda - \sin(\lambda-\alpha)\}}{\cos(\lambda-\alpha)}\right]^{1/2}\right\}$$

$$= \frac{2\alpha}{3}\frac{(1+\alpha\tan\lambda)}{(1-\alpha\cot\lambda)}\left[1 - \frac{3}{4}\alpha\cot\lambda\left(\frac{1}{3} + \frac{7}{16}\tan^2\lambda + \frac{N}{4}\tan\lambda + \frac{3}{4}N^2 - M\right)\right]$$

or $X = \frac{2\alpha}{3}(1 + \frac{\alpha}{30}\tan\lambda)$ - (A5)

where terms in a^2 are needed in *Y* to obtain the first order expansion of *X*.

Acknowledgement
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Characterizing Fuzz In Nonwoven Fabrics

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Abstract
The present work describes a cylindrical lighting system and its applications for objectively assessing the presence of fuzz in nonwovens. This cylindrical lighting system was designed to allow easy isolation and measurement of fuzz by illuminating the fuzz and suppressing the background. Images acquired under different conditions showcase the need for and the utility of a cylindrical lighting system. The characteristics of fuzz in nonwoven fabrics are extensively explored as a function of different bonding temperatures, abrasion cycles, and the direction of the abrasion force.

Introduction
Pilling of woven and knitted fabrics is a fabric-surface fault in which “pills” of entangled fiber cling to the cloth surface, giving a worn appearance to the garment. In contrast, fuzz is generally considered as a pre-stage of pill formation [1]. Pills ultimately break off the surface. In the case of nonwoven fabrics, abrasion results in the formation of more non-pillable fuzz than pillable fuzz because of the self-limitation of available fiber length by the presence of the bond sites. Therefore, generally pilling is a characteristic of woven or knitted fabrics, and fuzz is more commonly used for nonwovens.

Over the past several decades, more than 20 different test methods have been developed to evaluate pilling, but none can detect pills conveniently and objectively, or describe them comprehensively [2]. Objective and reliable methods are needed to estimate the effects of both fabric structure and abrasion-related variables on fuzz or pill formation.

During the same period, advances in personal computers, image capture and image analysis techniques have made it possible to use imaging techniques as relatively inexpensive research tools. Recent research on pills using these tools with microscopy or lasers has been reported [2-5]. Image analysis techniques have been used in an attempt to determine the pill grade instead of using the older method of comparing pill images with the corresponding images of a set of standard photographs [2, 3].

Fuzz in nonwovens is affected by the inherent anisotropy of their structure resulting from the orientation distribution of fibers as well as the bond patterns. To objectively identify and estimate fuzzing, we have developed a method that is capable of assessing changes easily and reliably. The utility of this system is demonstrated through its ability in characterizing fuzzing in a set of nonwoven fabrics.

Materials and Methods

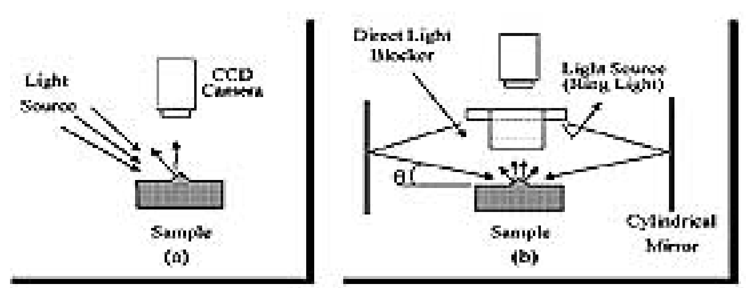
Thermally point bonded nonwovens

To investigate the role of bond strength on fuzz formation, test samples of two different nonwovens were produced at two-calendar roll temperatures, 150 and 180°C from dry staple uni-directional carded webs. The fibers were Poly (propylene). The final nonwoven fabrics had a weight of 20 g/yd^2.

Lighting Systems

Figure 1a shows a side lighting system similar to the one used by ref. [2] using a directional lighting source illuminated on one side of the sample. *Figure 1b* shows our cylindrical lighting system that uses a modified ring light and a reflector to illuminate the sample. By employing a round mirror, the desired lighting angle and the light angle distribution can be easily adjusted by changing the radius of the mirror and/or the light blocker and the distance between the ring light and the light blocker and/or the light blocker and sample. To minimize the distribution spread of the incident light, a large radius round mirror (200 mm) was employed. The size of the digitized image was 50 mm.

Figure 1
(A) SIDE LIGHTING SYSTEM SIMILAR TO THE ONE USED BY REF. 2
(B) CYLINDRICAL LIGHTING SYSTEM



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2. Address for correspondence

Nonwoven Fuzz and Image Analysis

The fabrics were abraded by a universal abrasion tester uni-directionally at 0, 45, and 90 degrees to form the fuzz. To determine the fuzzing mechanism, the abrasion cycles were varied from 0 to 300 at 20 cycle increments. Five images were obtained at each increment. The images were converted to black and white by using a segmentation procedure known as relaxation. This procedure has been discussed previously [6]. The geometrical features of the fuzz objects, including fuzz density referring to the total number of fuzz elements and fuzz area, were determined by procedures also previously discussed [7]. Using a transmitted directional lighting arrangement [see reference 6 for details], additional images were obtained for determining the fiber orientation distribution (ODF). ODF was determined from the two-dimensional Fourier Transform of these images [8]. The surface friction coefficient for each fabric was measured by using the Kawabata instrument (KES-FB-M4).

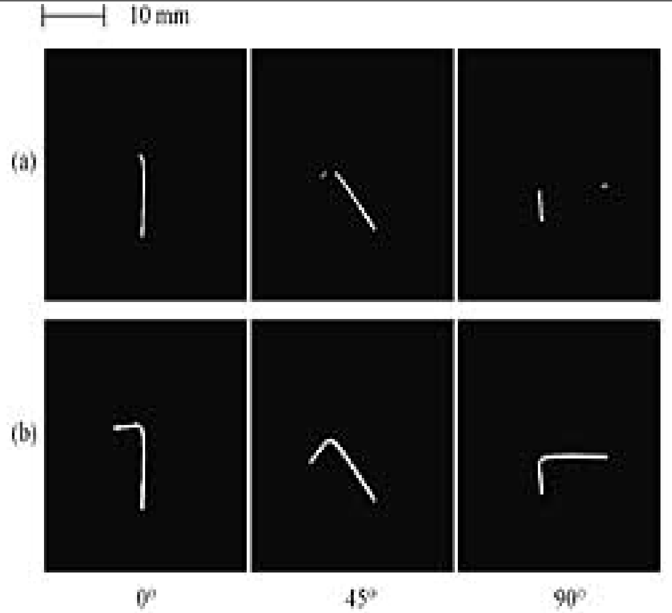


Figure 2
IMAGES AT DIFFERENT POSITION AFTER CONVERTING TO BLACK AND WHITE
WITH (A) SIDE LIGHTING AND
(B) CYLINDRICAL LIGHTING

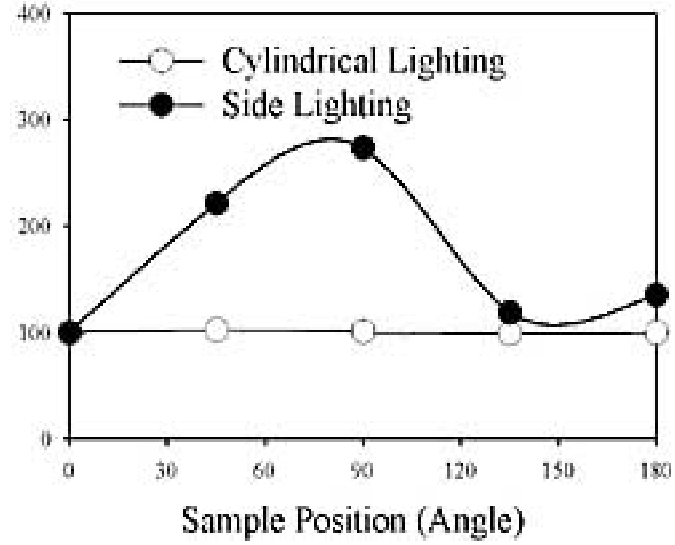


Figure 3
THE AREA FRACTION WITH THE SIDE AND CYLINDRICAL LIGHTING SYSTEMS

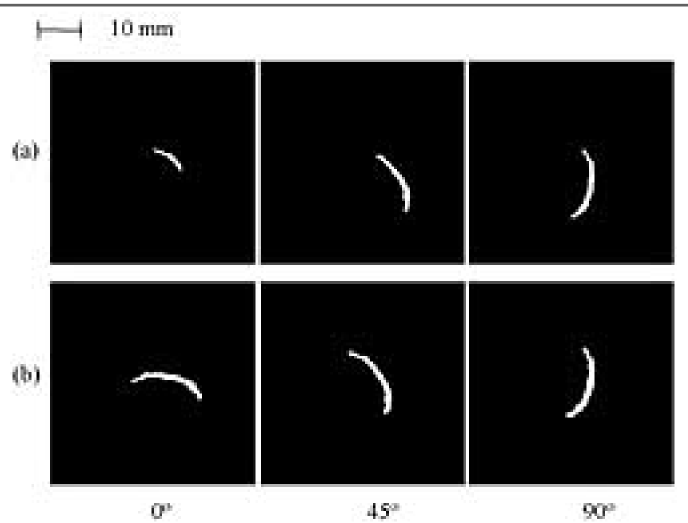


Figure 4
IMAGES DIGITIZED AT DIFFERENT POSITIONS
WITH (A) SIDE LIGHTING AND
(B) CYLINDRICAL LIGHTING

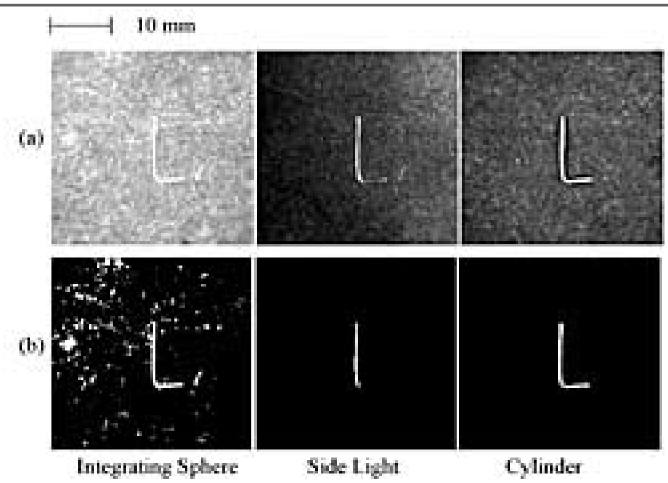


Figure 5
(A) IMAGES ACQUIRED WITH AN INTEGRATING SPHERE, SIDE AND CYLINDRICAL LIGHTING
(B) IMAGES AFTER CONVERSION TO BLACK AND WHITE

Results and Discussions

Cylindrical Lighting System

For comparison purposes, images of a piece of bent wire with uniform circular cross section and uniform surface properties were acquired under side and cylindrical lighting systems as shown in Figure 2. The images were digitized at 0, 45, and 90 degree angles. *Figure 2a* shows the images under the side lighting systems after the segmentation procedure. The wire is broken up into two or more non-continuous pieces when imaged at 0, 45 and 90 degrees even though the original object was one continuous piece. This is because any non-symmetrical and non-planar shape essentially casts different reflections and different shadows depending on the direction of the incident light. Using steep cylindrical incident lighting can minimize this problem. A steep lighting angle would help illuminate features such as fuzz while suppressing other details of the fabric structure. The area fractions of the objects from the two lighting systems (*Figures 2a and 2b*) were determined and are reported in *Figure 3.* As expected, the cylindrical system exhibits excellent directional stability. This is further demonstrated in *Figure 4,* where a fuzz is imaged at different positions.

Increasing the angle would reveal more of the fabric structure, making it more difficult to differentiate the fuzz from the fabric. At the same intensity, the cylindrical light system using steep lighting angle increases the contrast more than other systems (*Figure 5a*). Even at larger angles, the images obtained by using a cylindrical lighting system are better candidates for the segmentation procedure as indicated in *Figure 5b*.

Characterizing nonwoven fuzz with the cylindrical lighting system

Original images were converted to black and white by applying the relaxation threshold technique. To estimate the increased amount of fuzzing due to abrasion, the threshold value for the control sample was adjusted such that the fuzz area was close to zero, as shown in *Figure 6.* This threshold was then used for all other samples in the set.

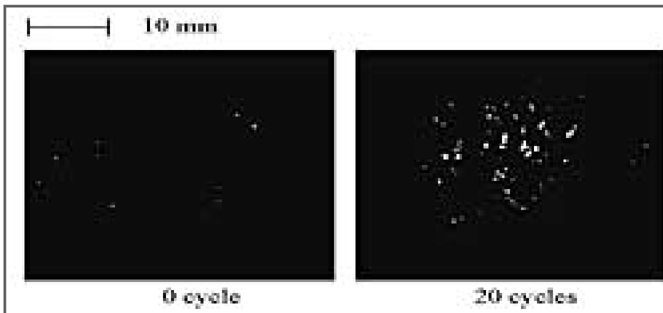
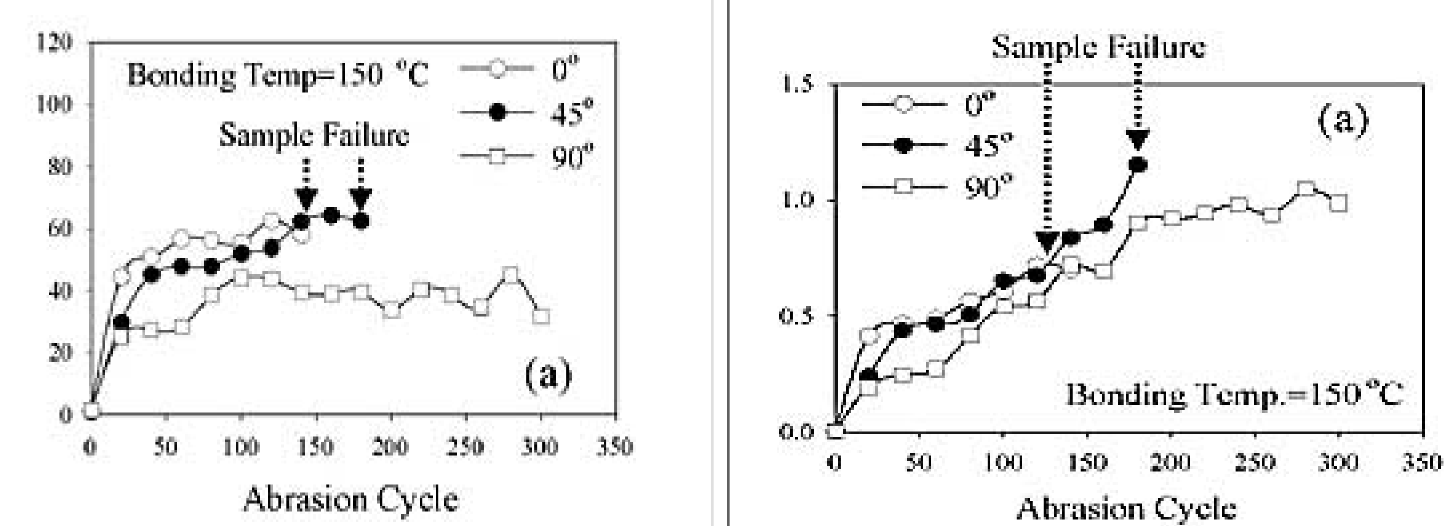


Figure 6
IMAGES AFTER 0 AND 20 ABRASION CYCLES



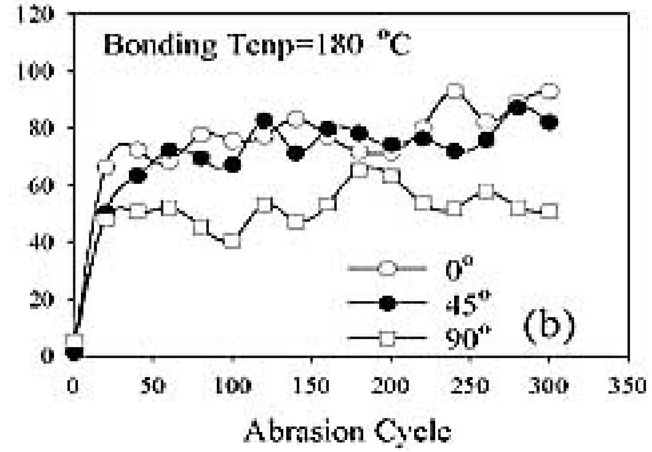


Figure 7
FUZZ DENSITY AS FUNCTION OF ABRASION CYCLE

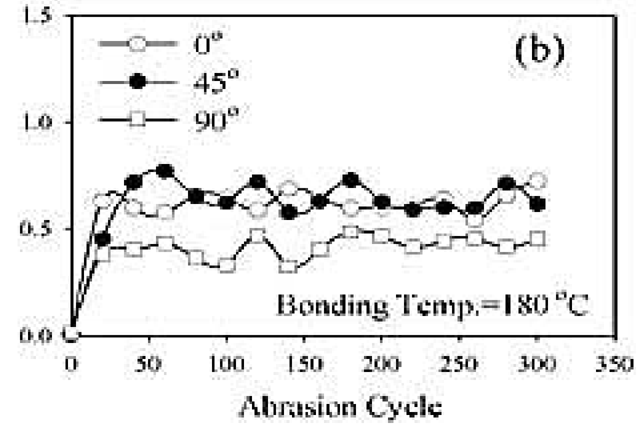


Figure 8
FUZZ AREA AS FUNCTION OF ABRASION CYCLE

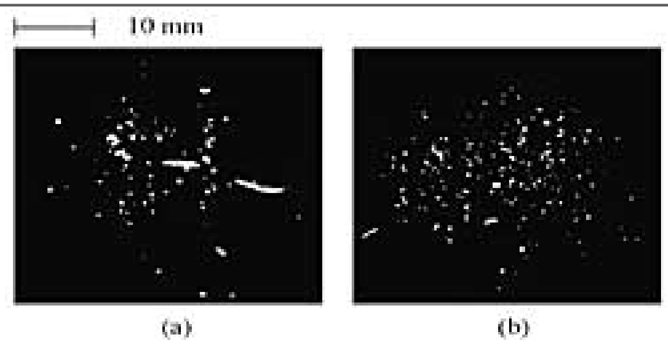


Figure 9
IMAGES AFTER 200 ABRASION CYCLES FOR NONWOVENS PRODUCED AT (A) 150º C
AND (B) 180º C BONDING TEMPERATURES

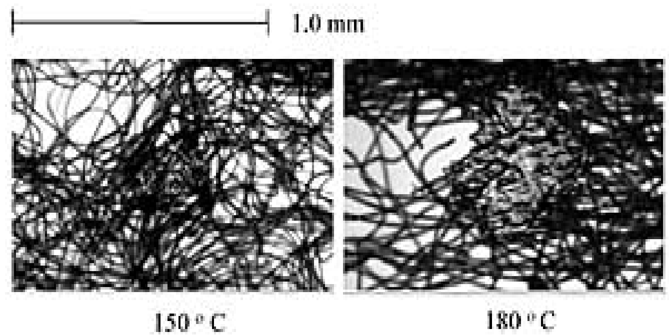


Figure 10
IMAGES AFTER (A) 300 ABRASION CYCLES
AND (B) TENSILE RUPTURE

The majority of test results follow a trend in which a maximum is initially seen followed by a plateau in fuzz density. This is similar to the trends observed for pilling. However in later stages of pilling, pill wear-off exceeds pill formation. If the fiber is strong, it is expected that the pill wear-off is delayed and the pill density remains close to the maximum [1]. In the case of our thermally point bonded nonwovens, a similar mechanism is observed where fuzz wear-off is delayed (*Figures 7 and 8*). Note, however, that fuzz density appears to be higher for the samples bonded at 180ºC (*Figure 7*) while the total fuzz area is higher for those bonded at the lower temperature of 150ºC (*Figure 8*). This indicates that the fuzz formed for the samples bonded at 180º are smaller. This is clearly seen in *Figure 9*.

As indicated above, the presence of bonded sites limits the available fiber segments length that would form the fuzz. This limitation varies with the bond strength and bond-to-bond distance. The basic difference relevant to fuzz formation in the nonwovens produced at the low (150ºC) and high (180ºC) bonding temperatures relates to their tensile strength. The higher bonding temperature results in a stronger bond. Consequently, rupture results in failure mainly at the fiber-bond interface. The rupture of the nonwoven samples bonded at the lower temperature is caused mainly by the separation of fibers from the bonded site due to shear forces. This is easily seen in the images shown in *Figure 10* by examining the images of ruptured samples following a tensile test. Weak bonding at the bond site easily allows for longer loosened fibers at those bond sites when the sample undergoes abrasion and can result in larger individual fuzz.

Directional characteristics of nonwoven fuzz

The fuzz properties at 20 abrasion cycles were investigated with additional abrasion tests at 135 degree.

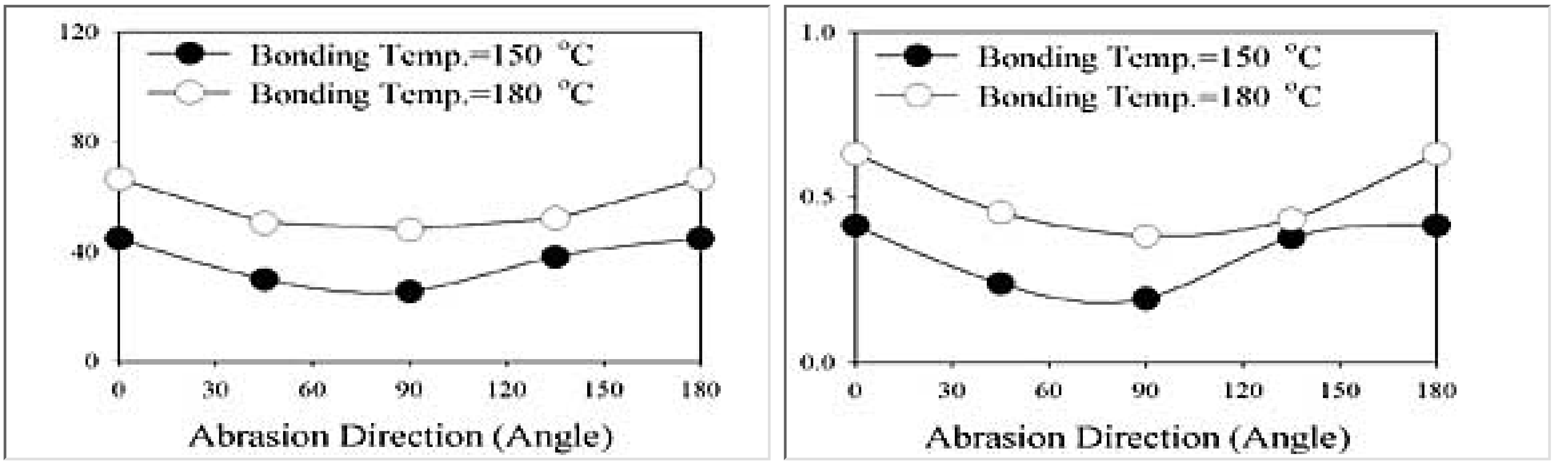


Figure 11
(A) FUZZ DENSITY AS FUNCTION OF ABRASION DIRECTION;
(B) FUZZ AREA AS FUNCTION OF ABRASION DIRECTION

Figure 11 shows that the total fuzz number and total area vary depending on the abrasion direction and the bonding temperature. The results at the 90 degree direction exhibit the lowest fuzz area and fuzz number. This is because the fibers are mainly oriented in the 90 degree direction as indicated by the orientation distribution function for the two samples shown in *Figure 12*. Because of this anisotropy, abrasion in the cross direction causes contact with the lateral side of the fibers while abrasion in the machine direction causes contact with the fibers along their length as demonstrated in *Figure 13*. Therefore, abrasion in the cross direction causes more damage than in the machine direction and is more likely to cause earlier fiber breakage and higher fuzzing. It is also found that the surface coefficient of friction will be higher in the cross direction (*Figure 14*).

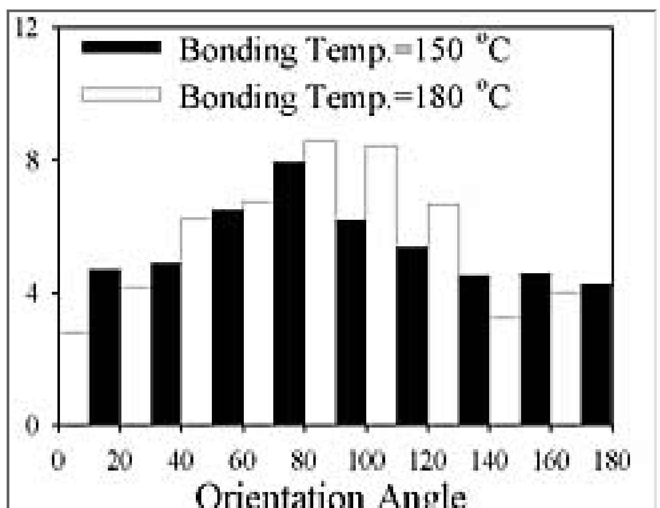


Figure 12
ORIENTATION DISTRIBUTION FUNCTION FOR NONWOVENS PRODUCED AT 150º C AND 180ºC BONDING TEMPERATURES

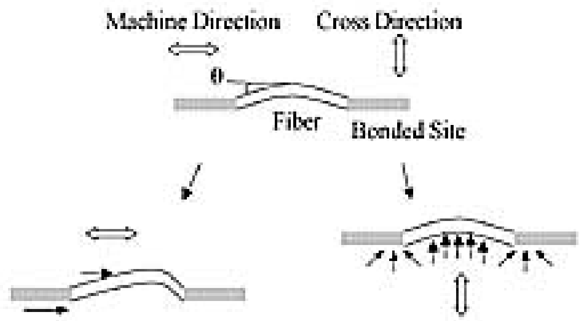


Figure 13
DIRECTION EFFECTS FOR NONWOVEN STRUCTURES ORIENTED IN THE MACHINE DIRECTION

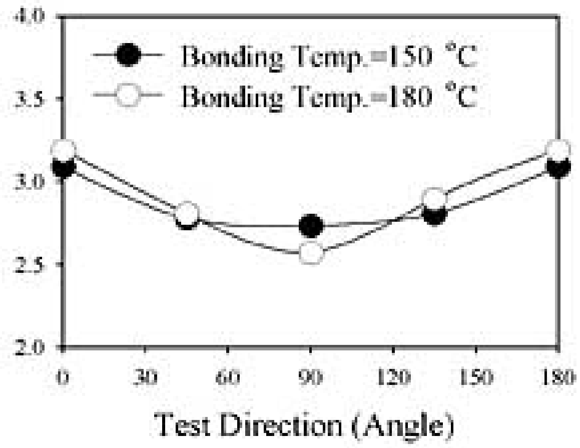


Figure 14
SURFACE FRICTION COEFFICIENT AS FUNCTION OF DIRECTION

Conclusion

We have demonstrated that fuzz can be easily quantified by using a cylindrical lighting system. The utility of this system is demonstrated by characterizing fuzz in a number of nonwovens. The properties of fuzz in nonwoven fabrics could be successfully explored for samples produced at different bonding temperatures as a function of abrasion cycles and abrasion directions.

The abrasion in the direction perpendicular to the dominant fiber orientation angle direction results in a higher fuzz density and total fuzz area than in other directions. With increasing bonding temperature, abrasion produces shorter and more non-pillable fuzz. At low bonding temperatures abrasion produces more pillable and larger fuzz. The technique is also useful in determining the degree of pilling in woven and knitted fabrics.

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Evaluating Operating Room Gowns: Comparing Comfort Of Nonwoven and Woven Materials

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EVALUATORS (PERFORMING DEXTERITY EXERCISE) AS THEY RATE SURGICAL GOWN COMFORT IN A CLIMATE CHAMBER AT NCSU CENTER FOR RESEARCH ON TEXTILE PROTECTION AND COMFORT (T-PACC)

Introduction

Wearer comfort is an important consideration in the performance of materials used in operating room (O.R.) gowns. The purpose of this research is to scientifically assess and compare the comfort properties of nonwoven and woven materials used for this important application.

This study combined two levels of investigation necessary for comprehensive comfort performance analysis: 1) Quantitative measurement of comfort related physical properties of test swatches using highly sensitive specialized instrumentation adapted to human response levels, and 2) a statistically significant subjective human subject garment comfort study. The data from these separate measures were integrated to identify the underlying material reasons for differences in comfort performance. Measurement was accompanied by concurrent subjective response assay to verify actual threshold sensitivity of the subjects to the instrumentally measured values.

Test Garments

The test garments were two types of commercially available operating gowns, identified as test garment A and B. Both gowns are identical in design, consisting of a simple one-piece garment that falls straight from the shoulder seams. The gowns have set-in sleeves, a wrap-around back panel that fastens at the neck and/or waist with tie/Velcro® closures. They have knitted sleeve cuffs to secure the edge at the wrist. Descriptions used in each of the gowns is as follows:

Identification	Gown Materials
A	Single-use spunlace nonwoven
B	Reusable woven cotton

The single-use gown (A) was tested in package form as received. The reusable gown (B) was commercially laundered before use and after each wear trial. Also, pressing after each laundering was required. For the test, evaluators wore a two-piece woven polyester/cotton scrub suit underneath the surgical gown with an operating room cap, mask and latex gloves. Evaluators also wore their own undergarments (males wore undershorts and females wore a bra and panties) and sneaker-type shoes with athletic socks.

Garment Wear Trials

Controlled garment wear trials were conducted using the state-of-the-art climate chamber available at the Center for Research on Textile Protection and Comfort at North Carolina State University (T-PACC).

Evaluators

Twenty males and nineteen females participated in the study, a total of 39 participants. Evaluators were obtained from the North Carolina State University, T-PACC subject pool, which includes persons, primarily students, who through a screening process were determined to be healthy nonsmoking individuals between 18 and 35 years of age. All evaluators received an initial orientation regarding requirements of participating in the wear trial.

Wear Trial Protocol

The wear trial protocol was deliberately designed to produce conditions of physical activity and environment that would cause differences in human response to the physical properties and characteristics of the operating gown garments to emerge. The wear protocol, based on the general approach developed by Hollies [1], was designed to include sweat generating activities that would represent a reasonable range of comfort conditions, for operating gown applications.

The protocol featured a five-period test sequence that included periods of physical activity alternating with periods of rest, in moderate and mildly warm environmental conditions. Sweat producing exercises were incorporated, including a mild aerobic step exercise and an exercise that required upper torso dexterity and mental skill *(Figure 1)*. Prior to initiating the wear trial, evaluators were required to sit quietly for 15 minutes in a moderate (21º, 65% RH) environment. This was done to bring the evaluators to a relaxed condition. The protocol proceeded as described in *Table 1*.

Table 1

WEAR TEST CHARACTERISTICS

Rating Period	Time (minutes)	Activity	Temperature ºC (ºF)	Relative Humidity (%)
1	10	rest	21 (70)	65
2	15	aerobics/ exercise*	21 (70)	65
3	15	rest	27 (80.6)	65
4	5	mental dexterity activity**	27 (80.6)	65
5	5	rest	21 (70)	65

* Mild stepping exercise with some arm movement.
** A competitive table-top game of manual skill.

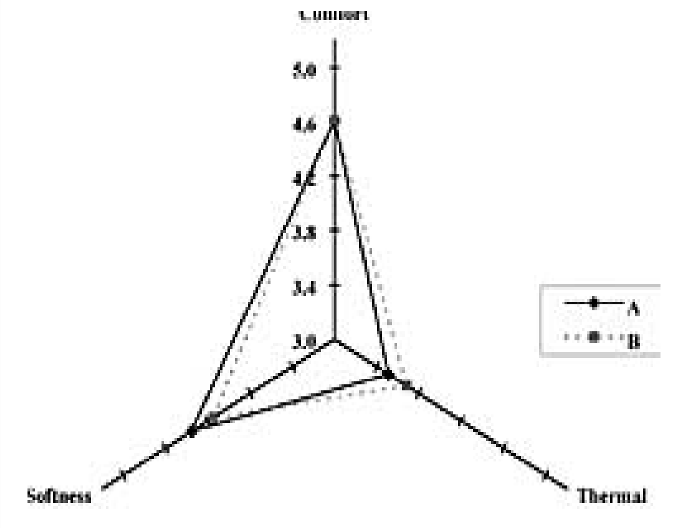

Figure 2
RATINGS OF GARMENTS FOR ALL PERIODS COMBINED

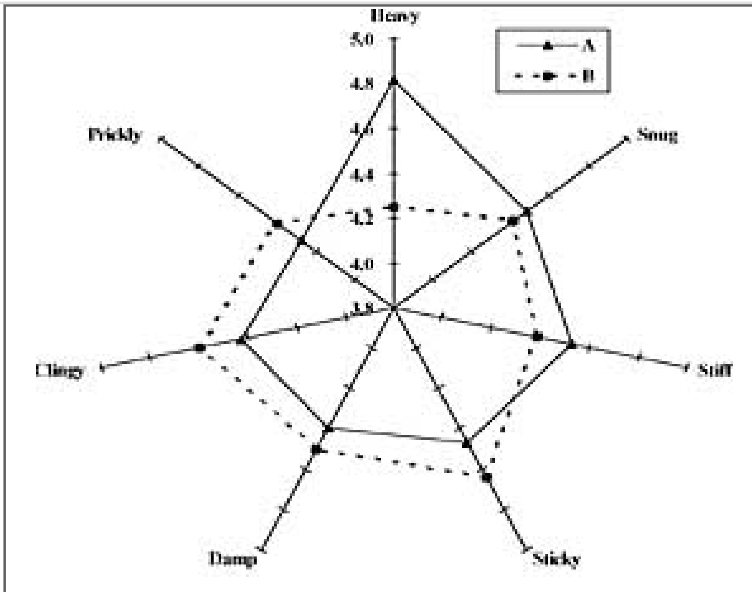

Figure 3
RATING OF GARMENTS FOR ALL PERIODS COMBINED

Test gowns were randomly assigned to evaluators, so that different types were worn in each test session. This practice assured that more independent ratings were obtained. Additionally, evaluators were instructed not to discuss the gowns or their ratings. An evaluation form was designed to obtain ratings of comfort and sensory tactile properties for each of the five periods of the test protocol. The first three items on the evaluation form require evaluators to rate overall comfort, warm-cool feeling, and softness of the material. The rating values of these items ranged from 1-7 as they appear on the evaluation form with 7 representing the most comfortable, coolest, and softest garment.

Table 2

LIST OF COMFORT DESCRIPTORS

Sensory Quality Descriptor	Associated Physical Property
Snug	Fit
Heavy	Weight
Stiff	Bending
Sticky	Moisture
Nonabsorbent	Moisture
Clammy	Moisture
Damp	Moisture
Clingy	Moisture
Prickly	Surface
Nonstretchy	Tensile
Scratchy	Surface

Eleven descriptor terms were selected to be representative of the fabric properties that are most relevant for operating gown applications. The descriptors are stated negatively because individuals are better able to discern degrees of tactile unpleasantness than degrees of tactile pleasantness. Values of 1-5 were assigned in these ratings with 1 = “totally” and 5 = “no sensation” (do not sense any negative quality). Higher values denote a more desirable quality. *Table 2* contains a list of the descriptor terms with the associated physical property of the fabric.

Wear Trial Results

The average rating of each comfort descriptor combined over all five periods of the wear test protocol, are shown in *Figures 2 and 3.* Selected comfort ratings are presented, by the specific rating period of the protocol in *Figures 4-10*. T-test analysis was used to determine if the difference between the mean ratings for the two operating gowns are statistically significant. The results of statistical analysis are presented in [Appendix A] to this paper.

Substantial differences do not emerge between test garments for the broad comfort descriptors of softness, thermal feeling and overall comfort vote, as these ratings are averaged over all periods of the wear test protocol *(Figure 2)*. This finding suggests that general or composite descriptors of evaluator comfort response are too diffuse to discriminate between these particular materials. On the other hand, perceived differences are more apparent when primary, or more specific ratings of skin contact discomfort sensations, such as stiffness or dampness, are used *(Figure 3)*.

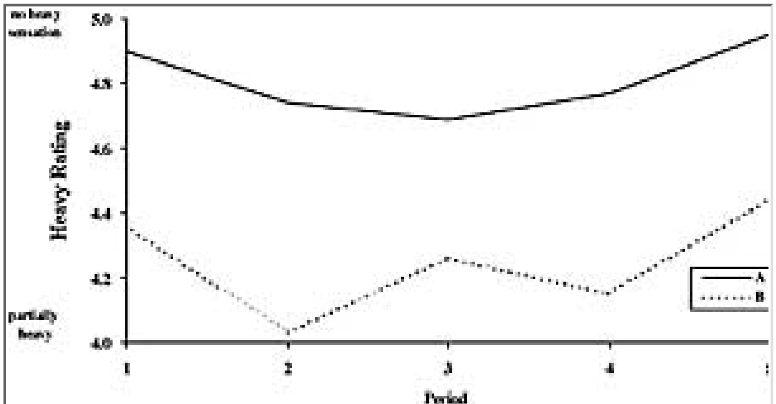

Figure 4
HEAVY RATING OF GARMENTS BY PERIOD

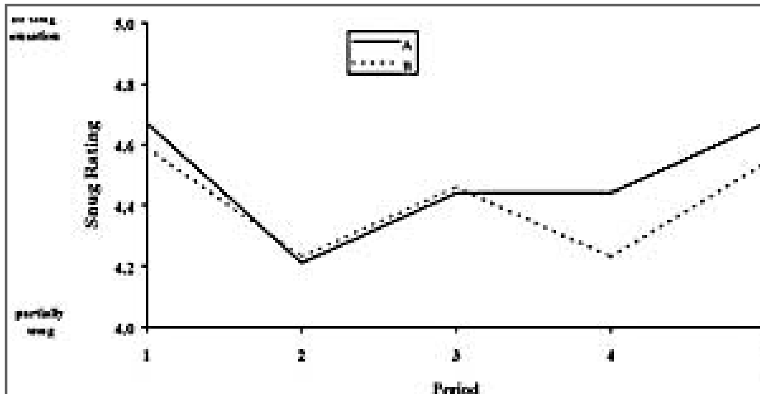

Figure 5
SNUG RATING OF GARMENTS BY PERIOD

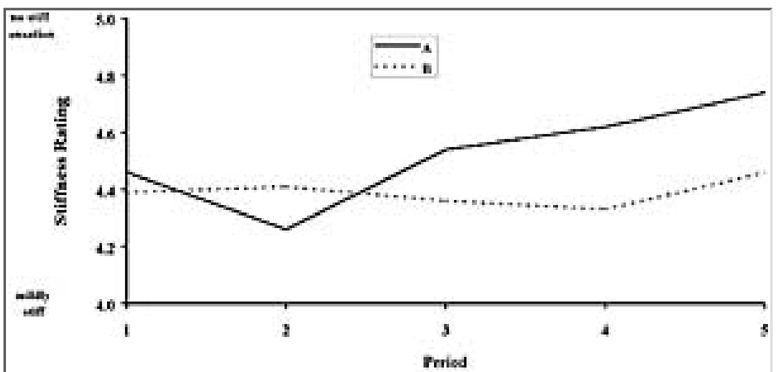

Figure 6
STIFFNESS RATING OF GARMENTS BY PERIOD

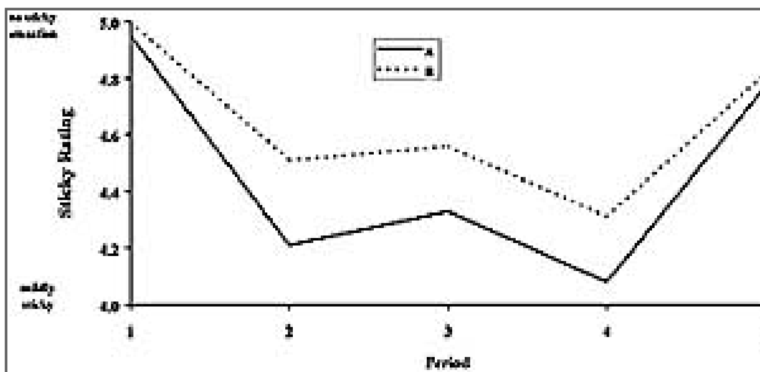

Figure 7
STICKY RATING OF GARMENTS BY PERIOD

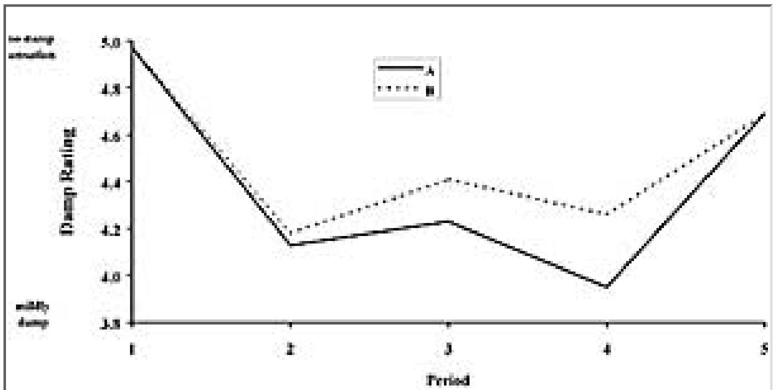

Figure 8
DAMP RATING OF GARMENTS BY PERIOD

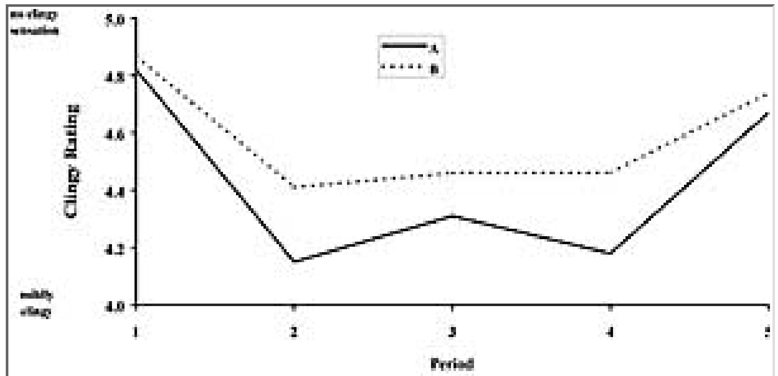

Figure 9
CLINGY RATING OF GARMENTS BY PERIOD

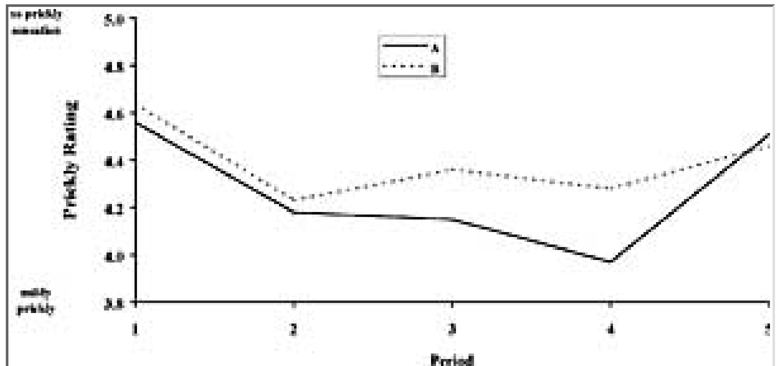

Figure 10
PRICKLY RATING OF GARMENTS BY PERIOD

The activity and/or environmental conditions significantly influenced comfort ratings. *Figures 4-10* show lower ratings for both gowns during periods that involve aerobic exercise (#2), or conditioning in a mildly warm environment (#3), and the mental dexterity activity in the warm environment (#4), than while sitting at rest in a moderate environment (periods #1 and #5). The results indicate that the nonwoven gown (A) is judged to be equal to the woven cotton gown (B) in the overall comfort vote. The two gowns are similar on most qualities evaluated, except that the cotton gown is always judged as being significantly heavier than the nonwoven gown. Differences associated with perceptions of stiffness and stickiness were also apparent in some rating periods, but these trends were not as strong as those associated with perception of garment heaviness.

Subtle differences are further revealed when comfort ratings are considered in discrete rating periods, as evaluators progressed through the activities called for in each period of the test protocol. Differences were most apparent during period #4. Period 4 included the mental dexterity activity performed following physical exercise. Period 4 was also a warm environment conditioning period. This part of the wear test revealed comparative advantages of each of the test gown materials. Besides perceived as being less heavy *(Figure 4)* the nonwoven gown (A) felt less snug *(Figure 5)* and less stiff *(Figure 6)* than the woven cotton gown in Period 4. These results suggest that the nonwoven gown possesses advantageous comfort qualities associated with the tactile properties of the material. After the mental dexterity activity, the woven cotton gown (B) felt less sticky *(Figure 7),* less damp *(Figure 8),* less clingy *(Figure 9),* and less prickly *(Figure 10)* than the nonwoven gown. All of these qualities are associated with skin moistness. Since cotton absorbs sweat formed on the skin, it contributes to reduce perceptions of skin wetness. The gown made with the nonwoven has less ability to absorb, or wick, the liquid from the skin surface.

Fabric Properties

This study included a comprehensive analysis of measured material properties associated with clothing comfort. Test samples were cut from operating gowns identical to those used in the comfort wear trials. Wash preparation for the instrument tested materials was identical to the preparation of equivalent test gowns used in the wear study: The nonwoven material (A) was tested "as received," the woven material (B) was tested after laundering. Unless otherwise stated, all test samples were conditioned for testing in a standard laboratory atmosphere (210C, 65% RH).

Heat and moisture transfer properties were measured using a sweating guarded hot plate, or skin model [2]. The Kawabata Evaluation System (KES) was used to measure fabric mechanical and surface properties [3]. Fabric structural properties measured included weight, thickness, bulk density and fiber volume fraction. The air permeability and wickability of the test fabric properties are summarized in *Table 3*. A description of test methods and measured parameters is given in the *Appendix B* to this paper.

Table 3

MEASURED PROPERTIES OF OPERATING GOWN FABRICS*

	Fabric	
Property	**A**	**B**
Structural		
Weight (oz/yd^2)	1.98	5.32
Thickness (mm)	0.48	0.69
Bulk Density (kg/m3)	139.5	261.5
Volume Fraction (%)	6.7	13.3
Air Permeability (ft3/ft2 min)	56.9	50.6
Heat & Moisture Transport		
Clo	0.426	0.414
Permeability Index (im)	0.455	0.374
Comfort Limit (watts/m2)	304	296
Wicking (cm/10 min)	0.0	3.4
Tactile		
KES: SMD (mm)	7.0	7.3
EMT (%)	3.8	12.8
G (gf/cm^2)	4.5	2.1
B (gf/cm^2)	0.13	0.10

* Results are averages of multiple readings on individual samples.

The results of the instrument measurements generally explain the subjective ratings produced during the garment wear trial. The lower material weight and thickness of the nonwoven garment fabric A translates to provide an advantage in evaluator ratings on certain mechanical properties. It is thinner, lighter in weight with lower bulk density than the woven cotton. These properties are expected to influence the material stiffness. The higher air permeability of fabric (A) associates with better moisture vapor permeability, as shown by the higher permeability index (im value) measured in the sweating skin heat transfer test. However, clo values and calculated comfort limits indicate that dissipation of body heat through these materials may not be the most critical factor differentiating comfort performance in these wear conditions.

The results of Kawabata (KES) testing of mechanical hand properties show that surface roughness (SMD value) and bending rigidity (B value) are generally comparable for both materials. Stiffness and stretchability are qualities where ratings fail to support predictions from the instrument measurements. The nonwoven (A) does have a significantly higher shearing stiffness (G value) but was judged by evaluators as being less stiff than the cotton material. Nonwoven materials typically are less shearable than woven fabrics. The bending rigidity, which was similar for the two materials, may be a stronger determinant of stiffness than the shearing property. Differences in stretch were not detected in the wear trials but the woven cotton (B) had much higher tensile extensibility (EMT value).

The woven cotton fabric shows an ability to wick liquid moisture. This, undoubtedly, explains comfort advantages associated with skin wetness.

Conclusions

Both the instrument and garment wear trial are useful for discriminating a variety of subtle properties that contribute to the cumulative perception of the comfort of these particular woven and nonwoven operating gowns. These results point to the following conclusions:

- The nonwoven (A) is generally equivalent to the cotton gown (B) in all specific comfort descriptors, except weight and stiffness, where it has an advantage. These mechanical advantages translate into the perception of added mobility in the gowns, especially during periods of mental dexterity activities following skin sensitization with sweat producing exercise and/or warmer environments.

- At the same time, because of its greater moisture absorption capacity, the cotton gown (B) has an advantage in the perception of comfort sensations associated with feeling of skin or clothing wettedness. The moisture management advantages became apparent following sweat-producing mental and physical activities.

The techniques used in this study effectively distinguish differences in comfort performance of operating gowns. However, overall comfort descriptor ratings are shown to be too diffuse to distinguish between these two operating gowns for this range and application. When a general comfort impression is sought, no statistically significant difference is obtained between the test garments despite objective structural differences. Differences in perception show up only on more specific comfort ratings, which break down comfort sensations into their tactile and moisture-related components.

In summary, the wear trial protocol provided comprehensive and informative data for assessing overall tactile, heat and moisture transport and aesthetic response. This scientific approach to wear comfort evaluation is useful in identifying the underlying physical causes of discomfort and pointing to the instrument measures that can quantify them.

Additional research studies that use these laboratory techniques to explore the factors that control the comfort of operating gowns, would be of considerable scientific and practical value.

Acknowledgements

The authors gratefully acknowledge the support of E.I. du Pont and SCA Molnlycke in this project.

References

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APPENDIX A

Table A1

Average Comfort Descriptor Ratings (Standard Deviation) Combined Over All Five Test Periods (n = 39)

Sensory Term	Garment A	Garment B	t-test
Comfort Rating (1 - 7)	4.61	4.61	N
	(1.00)	(1.11)	
Thermal Feeling (1 - 7)	3.51	3.68	N
	(1.04)	(1.05)	
Softness (1 - 7)	4.35	4.15	N
	(1.22)	(1.30)	
Snug (1 - 5)	4.49	4.41	N
	(1.00)	(1.00)	
Heavy (1 - 5)	4.81	4.25	S
	(1.00)	(1.00)	
Stiff (1 - 5)	4.52	4.39	N
	(0.62)	(0.49)	
Sticky (1 - 5)	4.47	4.64	S
	(0.16)	(0.27)	
Nonabsorbent (1 - 5)	4.46	4.64	t
	(0.27)	(0.16)	
Clammy (1 - 5)	4.54	4.46	N
	(0.39)	(0.16)	
Damp (1 - 5)	4.39	4.50	N
	(0.00)	(0.16)	
Clingy (1 - 5)	4.43	4.59	N
	(0.75)	(0.77)	
Prickly (1 - 5)	4.27	4.39	N
	(0.80)	0.92)	
Non-stretchy (1 - 5)	4.37	4.36	N
	(0.76)	(0.73)	
Scratchy (1 - 5)	4.21	4.23	N
	(0.79)	(0.88)	

Table A2

Average Comfort Descriptor Ratings by Period (n = 39)

Garment	Period 1	2	3	4	5
Average Heavy Ratings					
A	4.90	4.74	4.69	4.77	4.95
B	4.36	4.03	4.26	4.15	4.44
t-test	S	S	S	S	S
Average Snug Ratings					
A	4.67	4.21	4.44	4.44	4.67
B	4.59	4.23	4.46	4.23	4.54
t-test	N	N	N	t	N
Average Stiff Ratings					
A	4.46	4.26	4.54	4.62	4.74
B	4.39	4.41	4.36	4.33	4.46
t-test	N	N	N	S	N
Average Sticky Ratings					
A	4.95	4.21	4.33	4.08	4.77
B	5.00	4.51	4.56	4.31	4.82
t-test	t	S	t	t	N
Average Damp Ratings					
A	4.97	4.13	4.23	3.95	4.69
B	4.97	4.18	4.41	4.26	4.69
t-test	N	N	N	t	N
Average Clingy Ratings					
A	4.82	4.15	4.31	4.18	4.67
B	4.87	4.41	4.46	4.46	4.74
t-test	N	N	N	t	N
Average Prickly Ratings					
A	4.56	4.18	4.15	3.97	4.51
B	4.64	4.23	4.36	4.28	4.46
t-test	N	N	N	t	N

N = Insignificant difference between means at 90% confidence level *S = Significant difference between means at 90% confidence limit* *t = Significant trend*	*N = Insignificant difference between means at 90% confidence level.* *S = Significant difference between means at the 90% confidence level.* *t = Significant trend.*

APPENDIX B

Fabric Structural Properties

Weight

Weight was measured according to ASTM D 3776 small swatch option. Three 5 in. x 5 in. specimens were weighed on an analytical balance and the weight calculated in mass per unit area (oz/yd^2).

Thickness

The thickness of the fabric samples was determined using the KES-FB3 compression tester. The thickness of a 2 cm^2 area was measured at 0.5 gf/cm^2 and is reported in millimeters (mm).

Bulk Density

The bulk density is calculated from the fabric areal weight (kg) and volume (m3): Bulk density = weight/volume (kg/cubic meters).

Air Permeability

Air permeability is measured using the KES-F8-API permeability tester. A constant rate of air flow (in Kpa.s/m) was passed through a known area of fabric into the atmosphere. The air resistance of the specimen is directly measured using low sensitivity in the range of 0.1 to 26.00 (cubic feet/square.minute).

Heat and Moisture Transport Properties

Thermal comfort properties determined were calculated from measures made with skin model hot plate instrumentation. The reported comfort parameters are described below.

Heat Transfer: Dry and Sweating Skin Tests, including Insulation,

Permeability Index, and Comfort Limits

Heat transfer is the measure of the heat flow from the test plate (heated to a skin surface temperature of 35^{o}C) through the material into the test environment (21^{o}C, 65%RH). It is determined in $Watts/m^{2o}C$ for dry skin and wet skin conditions. Comfort parameters, calculated from heat transfer values, include:

a. Clo is a unit of thermal resistance which indicates the insulating ability of the test material. A clo value of 1 represents a typical man’s business suit and is expected to maintain thermal comfort for a person in a normal indoor environment.

b The im value, or permeability index, indicates moisture-heat permeability through the material on a scale of 0 (totally impermeable) to 1 (totally permeable). This comfort parameter indicates the effect of skin moisture on heat loss.

c. Comfort limits are the predicted metabolic activity levels that wearers may sustain and maintain body thermal comfort in the test environment. The comfort limit reported in this paper is based on 20% evaporative heat loss.

Wicking

The water transport rate is measured using to a vertical strip wicking test. In this test, one end of a fabric strip (25mm wide X 170 mm long) is clamped vertically with the dangling end immersed to about 3 mm in distilled water at 21ÞC. The height to which the water is transported along the strip is measured at 1, 5 and 10 minute intervals and reported in centimeters (cm). Higher wicking values show greater liquid water transport ability.

Mechanical Tactile (KES) Properties

KES instruments measure mechanical properties that correspond to the fundamental deformation of fabrics in hand manipulation and clothing wear. Different tests are performed using KES, generating different mechanical characteristics. Each test and its specific parameters is listed below. A standard specimen size of 20 cm x 20 cm is used in three replications. All measurements are directional, except for compression, and are made in both the warp/machine direction, and in the filling/cross direction of the sample.

Tensile

The tensile test, done on the KES-FB1 Tensile-Shear Tester, measures the stress/strain parameters at the maximum load of 50 gf/cm for nonwoven fabrics and 500 gf/cm for woven fabrics. The reported tensile parameter is: EMT - extensibility, percent strain at maximum load of 500 gf/cm (100% = complete elasticity, 0% = complete inelasticity).

Shearing

In shear testing, opposing parallel forces are applied to the fabric by the KES-FB1 Tensile-Shear Tester until a maximum offset angle of 80 is reached. A tension load of 10 gf/cm was applied to the specimen in shearing. Shearing stiffness is the ease with which yarns/fibers slide against each other resulting in soft/pliable to stiff/rigid structures. The reported shear property is:

G — shear stiffness, gf/cm.degree (higher G value means greater stiffness/resistance to the shearing movement).

Bending Bending, measured with KES-FB2 Bending Tester, is a measure of the force required to bend the fabric approximately 150º. The reported bending parameter is:

B — bending rigidity per unit fabric width, gf.cm^2/cm (higher B value indicates greater stiffness/resistance to bending).

Surface

The surface properties of friction (resistance/drag) and surface contour (roughness) were determined using the KES-FB4 Surface Tester. The reported surface property is:

SMD — geometric roughness, micron
(higher SMD corresponds to a geometrically rougher fabric surface).

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Determining the Dynamic Efficiency With Which Wiping Materials Remove Liquids From Surfaces

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Abstract
While a number of tests exist to characterize wiping materials for their capacity and rate of sorption, none of these static tests describe how effectively a wiper will remove liquid from a surface under dynamic conditions of use. This paper describes the development and application of a test for dynamic wiping efficiency, or "wipe-dry," under conditions similar to manual wiping operations. The method was used to characterize 11 commercially available fabrics used as wipers in industrial, food service, and cleanroom applications. As a class, fabrics constructed by hydroentangling generally outperformed those made by other means. Of those, fabrics with bulky character exhibited superior wipe-dry. Also included are comparative data of sorbent capacity, rate of sorption and bursting strength.

Introduction
Many tests exist for assessing the suitability of fabrics for their use as industrial, food service, or cleanroom wiping materials. While some procedures address cleanliness (particles, ions, non-volatile residue, linting) and strength (tensile strength, bursting strength, abrasion resistance), others address the functional characteristics of wiping materials with a view toward quantifying their sorptive properties: viz., the rate and capacity with which wipers can sorb liquids.

Foremost among the tests for quantifying sorptive capacity properties of wiping materials are those found in IST 10.2(98) from INDA, Association of the Nonwoven Fabrics Industry [1]. In fact, the test used in this study for quantifying the intrinsic sorptive capacities of the wiping materials in this study is the one cited in this Standard. Other methods, however, also exist to measure capacity: the basket test [2], the test for intrinsic and extrinsic capacity [3,4], and the demand absorbency test (GATS) [5,6]. Some of these same tests as well as others are used to measure the rate of sorption: the intrinsic and extrinsic rate test [3], the basket test [2], the time to half sorption [7], the water drop test [8], demand absorbency test (GATS) [5,6], and the wicking rate test [2]. While all of these tests permit (albeit to differing degrees of scientific validity) one to differentiate wiping materials according to their ability to sorb liquids, each test is somewhat static in nature. None of them addresses, directly or indirectly, the ability of a wiper to remove liquid from a surface in a dynamic fashion, that is to say, under pressure and under conditions similar to those which might exist during manual wiping operations.

During the manual wiping up of a pool of fluid with a wiper, liquid is, to be sure, sorbed into the fabric. At the same time, however, other forces also come into play which act counter to this sorptive process: 1) the pressure exerted during wiping can either retard sorption or force already sorbed liquid out of the wiper, 2) because of surface tension differences, competition for the liquid exists between the wiper and the fluid as well as between the surface and the fluid. Putting it more simply, the net result is that liquid is sometimes left behind on wiped surfaces. Not all wipers can "wipe dry" even when their capacities, as determined by static tests such as those mentioned above, are not exceeded. This is particularly true for items made from hydrophobic synthetic polymers, which frequently leave trails or droplets of water behind in the wake of manual wiping operations.

In this paper, tests are described for the dynamic removal of a liquid from a surface.

Background

Macfarlane [9] recently published a test for measuring the ability of a fabric to wipe a surface dry. In this test, a wiper is affixed to the bottom side (7 cm by 7 cm) of a 1-kg sled. The sled (*Figure 1*) is placed onto a 1-mL pool of liquid on a melamine surface; time is allowed to elapse, then the sled is pulled a distance of 1 m at a rate of 50 cm/s. The wiper, now wetted with liquid, is removed from the sled and its mass compared to its previously determined dry mass. Efficiency of liquid removal is defined as the percentage of the liquid challenge removed from the surface. Oathout [10] modified this technique for cleanroom use, selecting a 11.4 cm by 11.4 cm (4.5 in. x 4.5 in.) sled to accommodate quarterfolded samples 22.8 cm (9 in.) on a side, used a 50 cm stainless steel pan to contain particles to be enumerated after wiping, and elected a speed of 25 cm/s. A liquid challenge range up to 130% of wiper capacity was placed in front of the sled rather than under it to more accurately simulate spill removal. This test was called Dynamic Wiping Efficiency. In the sections that follow, we first discuss the wiping materials used for this current study and their characteristics. This is followed by descriptions, data and discussion of the tests for dynamic wiping efficiency as applied to a range of industrial, food service and cleanroom wiper fabrics.

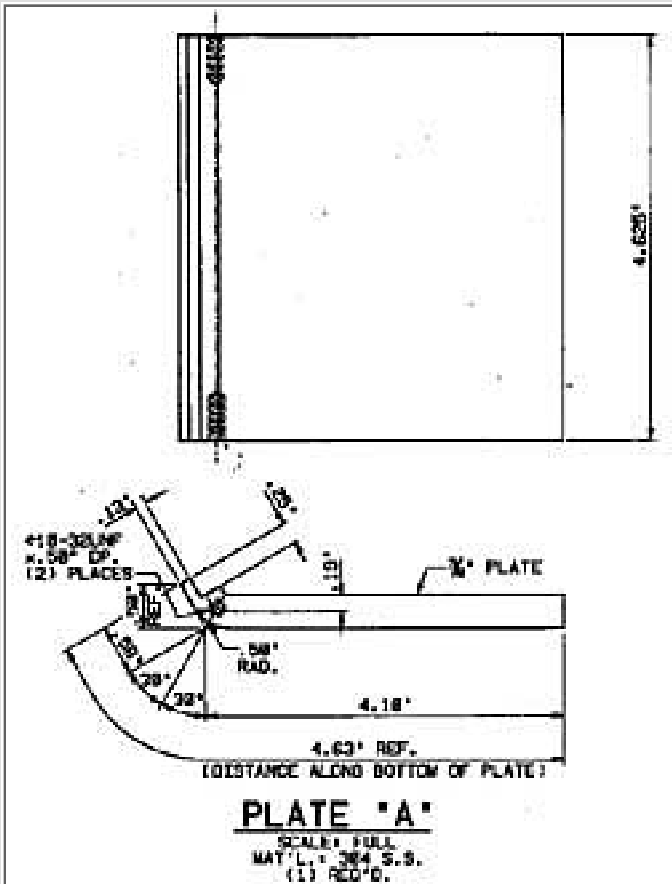

Figure 1
DRAWING OF SLED
(For SI Units in millimeters, multiply inches by 25.4)

1. Wiping Materials

This study was conducted using 11 wiping materials, representative of items commonly used in industrial, food service, and cleanroom applications and spanning a range of composition, construction, basis weight and cost. Selected physical characteristics are given in *Table 1*, including basis weight, composition, method of construction, etc. Seven of the items were nonwoven:

Table 1

PHYSICAL CHARACTERISTICS OF THE 11 WIPING MATERIALS IN THIS STUDY

Wiper	Basis Weight[a] [g/m^2]	Construction and Composition
Nonwoven		
A	90.9	woodpulp, binder; modified papermaking process; double re-creped; white; quarter folded individual plies, 0.33 m x 0.33m (12.9" x 13")
B	66.6	55% woodpulp/45% polyester; hydroentangled, blue, non-creped, 0.36 m x 0.43 m (14" x 17")
C	80.0	55% woodpulp, 45% polyester; hydroentangled white, creped and embossed with logo, 0.30 m x 0.34 m (12" x 13.25"), quarter folded
D	109	38/34/28% nylon/woodpulp/polyester; stitchbonded bulked, white, individual sheets (0.46 m x 0.35 m) (17.9" x 13.7")
E	71.7	70% rayon/30% polyester, 8 mesh, hydroentangled yellow, binder and surfactant, 0.21 m x 0.19 m, (8.14" x 7.7") quarter folded (0.42m x 0.38 m unfolded)
F	13	82% rayon/18% polyester, binder; hydroentangled with herringbone pattern; white with red stripe and logo, quarterfolded (0.30 m x 0.17 m folded) (0.60 m x 0.34 m unfolded)
G	37.8	100% polyester, surfactant treated, hydroentangled, white, individual plies, 0.24 m x 0.23 m (9.2" x 8.9")
Knitted		
H	150	100% polyester knit, cleanroom laundered, sealed edge knit, white, individual plies, 0.21 m x 0.22 m (8.3" x 8.7")
I	153	polyester; knitted; white; cleanroom laundered individual plies, 0.22m x 0.22 m (8.7" x 8.7")
Woven		
J	170	cotton; woven; white, individual plies, 0.21 m 0.22 m (8.6" x 8.4")
Meltblown		
K	71.0	polypropylene, surfactant; meltblown; thermally bonded to depict woven pattern; blue; perforated sheets (0.30 m x 0.43 m)

a = average basis weight of the plies tested

- one 100% woodpulp with binder, papermaking process
- six hydroentangled
  - non-creped woodpulp/polyester combination
  - creped, embossed woodpulp/polyester combination
  - stitchbonded woodpulp/nylon/polyester combination
  - rayon/polyester composition treated with binder and surfactant
  - rayon/polyester composition treated with binder
  - 100% polyester treated with surfactant

Table 2
SORPTIVE CAPACITIES AND RELEASABLE PARTICLES FOR THE 11 WIPING MATERIALS IN THIS STUDY

Wiper	Basis Weight [g/m^2]	Sorbent Capacity Ai [mL/g]	Sorbent Capacity Ae [mL/m^2]	Rate of Sorbency Ri [mL/g/s]	Rate of Sorbency Re [mL/m^2/s]	Mullenburst Dry [psi]	Mullenburst Wet [psi
A	90.9	5.60	509	2.98	270	7.2	9.0
B	66.6	4.31	287	9.46	632	49	41
C	80.0	5.18	409	14.9	1159	50	45
D	109	3.84	418	8.89	967	116	101
E	71.7	6.57	471	31.0	2208	36	36
F	135	5.29	713	6.82	920	52	32
G	37.8	5.93	224	47.4	1784	90	44
H	150	2.53	380	0.67	100	>120	>120
I	153	3.05	466	9.53	447	>120	>120
J	170	1.55	263	1.96	333	>120	>120
K	71.0	5.39	383	2.61	184	7.8	11.2

Two of the fabrics were knitted of 100% polyester, one with sealed edges and one without. A woven cotton twill fabric and a meltblown thermal bond fabric rounded out the series. All of the items were obtained commercially.

In *Table 2*, the static sorptive capacities and rate of sorption for the eleven wipers are given, as well as bursting strength as determined by standard tests [1,11]. As will be described later, the values for capacity were used to determine the per-ply capacity for each of the wipers. The values for basis weight, extrinsic and intrinsic sorptive capacity, extrinsic and intrinsic rate of sorption are given below, and are taken from the standard method [1].

$bw = m_d/[n \times l \times w]$ (1)

$A_e = [(m_w - m_d)/0.997]/[n \times l \times w]$ (2)

$A_i = A_e/bw$ (3)

$R_e = [(mw - md)/0.997[l \times w]/t_n$ (4)

$R_i = R_e/bw$ (5)

where:

n is the number of plies

bw is the basis weight [g/m^2]

A_e is the extrinsic sorptive capacity [mL/m^2]

A_i is the intrinsic sorptive capacity [mL/g]

R_e is the extrinsic rate of sorption [$mL/m^2/s$]

R_i is the intrinsic rate of sorption [mL/g/s] and 0.997 is the density of water at 25^{o}C.

2. The Test For Dynamic Wiping Efficiency

(DWE) For this study, we drew on the earlier methods of Macfarlane [9] and Oathout [10], using elements of each. We opted for a wiping speed of 25 cm/s as being more realistic than 50 cm/s. For the surface to be wiped, we substituted a 2 ft x 4 ft stainless steel plate typical of the food service industry. We used a 1-kg sled whose footprint had dimensions of 114 mm (4.5 in.) on an edge, this to accommodate wiping materials quarter-folded from a common size of 229 mm by 229 mm (9 in. by 9 in.).

Instead of a single challenge consisting of 1 mL of water, we used a 10 mL challenge and a challenge equivalent to 50% of the wipers' sorptive capacity as measured by their A_i's.

Rather than placing the fabric and sled directly onto the liquid pool and then allowing time to elapse before beginning the 1-m traverse, we placed the liquid challenge in front of the sled and then pulled the sled into and through the pool, a situation which resembles more closely the phenomenon of wiping up real spills.

The following equipment, or its equivalent, is needed:

- balance: top loading, shielded, 0.01-g readability
- plate: stainless steel, 61 cm (2 ft) x 122 cm (4 ft)
- sled: stainless steel, 1 kg, 114 mm x 114 mm base; a curved leading edge on the base of the sled forms a lip to which the quarter-folded sample is attached using a spring-loaded clip. Two stainless steel screws are affixed to either outboard edge of the sled in the leading curved edge.
- dispenser: Brinkmann Bottletop Buret, Model 25, for reproducible and accurate delivery of volumes of liquid
- water: because it was convenient (but unnecessary) to do so, RO/DI water was used.
- apparatus: a polyester string is attached to the sled at the stainless steel screws, forming a yoke. A second polyester string (~4 ft long) is attached at the midpoint of the yoke. The string is used to

pull the sled at a rate of ~25 cm/sec. A 60 hz motor equipped with a sheave of 25 cm circumference was used as a capstan device to pull the sled at a constant and uniform speed.

The procedure is as follows:

Figure 2
ILLUSTRATION OF DYNAMIC WIPING EFFICIENCY APPARATUS

1. Quarter-fold a single ply of wiping material (cut to 9 in. by 9 in.) and determine its dry mass, M_d, to the nearest 0.01 g.
2. Clip the quarter-folded wiper to the sled so that the single convex fold is at the leading edge.
3. Position the sled at one end of the stainless steel plate with the leading edge perpendicular to the axis of the long dimension of the plate. (*Figure 2*)
4. If the intrinsic sorptive capacity, A_i, of a wiper is not already known, determine it on a separate ply of the material using the referenced procedure [1,4]. From the calculated A_i and the measured mass of each wiper, calculate the per-ply capacity A_{ip} [mL/g] for each wiper. This quantity is needed in order to calculate to volume representing a 50% challenge. (Alternately, the per-ply capacity may be determined directly by saturating and draining individual plies as prescribed in the method [1,4].)
5. Using the dispenser, place the desired volumetric challenge of water, v_c, onto the plate at a point a few centimeters in front of the leading edge of the sled.
6. Using the string, pull the sled at a rate of ~25 cm/s through the water and along the long axis of the tray, a distance of 100 cm. This is achieved by loosely wrapping the string around the capstan/sheave and applying tension to provide constant speed.
7. Remove the folded wiper from the sled, determine its wetted mass, mw, and, by difference, the mass of water sorbed. Calculate, using the density of water (0.997 g/mL at 25^o) the volume of water sorbed, v_s. Calculate the dynamic wiping efficiency, DWE, by dividing the volume of water sorbed, v_s, by the volume of the challenge, v_c, and converting to a percentage:

$$DWE = 100\ [(m_w - m_d)/0.997]/v_c = 100\ v_s/v_c \qquad (6)$$

In this work, the wipers were challenged with v_c's of 10 mL as well as with a volume calculated to be 50% of the sorptive capacity ($0.5A_{ip}$) of the respective wiper. The constant volume challenge data are presented in *Table 3*, while the 50% capacity challenge data are presented in Table 4. Six replicates were run in each case. From a user's point of view, the constant volume challenge data may be more useful than a relative basis, since it expresses how well a particular wiper, regardless of basis weight, removes a spill of a given volume.

The top two performers, about tied with DWE's of 98+%, were hydroentangled fabrics with a bulky character, imparted either by creping ("C") or stitchbonding ("D"). The non-creped lighter weight hydroentangled fabric ("B") turned in noticeably poorer performance versus the creped item ("C"). Following the leaders in second place was the hydroentangled rayon/polyester composite with binder and surfactant added ("E"). By way of comparison, a similar fabric ("F") with even higher rayon content, but presumably lacking a surfactant, came in 7% lower, with a DWE of less than 90%. Turning in the poorest performance of "wipe-dry" was the spunbonded surfactant-treated polypropylene and the sealed-edge knit polyester used as a cleanroom wipe. The remaining fabrics occupied a middle ground of performance, (apparently acceptable, since all fabrics are sold commercially), yet clearly lagging the top performers.

Table 3

DYNAMIC WIPING EFFICIENCY FOR 10 ML CHALLENGE OF THE 11 WIPERS IN THIS STUDY

	Cap/ ply [mL]	Challenge [% of Cap.]	DWE [%]	σn-1
A	22.97	44	93.6	2.56
B	13.85	72	92.1	2.13
C	17.30	58	98.2	0.833
D	22.73	44	98.6	0.398
E	23.62	42	97.1	0.350
F	37.54	27	89.9	4.77
G	10.85	92	94.0	1.01
H	12.71	79	91.3	1.23
I	22.83	44	95.3	3.17
J	12.40	81	92.8	1.92
K	19.76	51	87.4	5.64

Table 4

DYNAMIC WIPING EFFICIENCY FOR CHALLENGE OF 50% CAPACITY FOR THE 11 WIPERS IN THIS STUDY

	Cap/ ply [mL]	Challenge for ~50% Cap. [mL]	Pickup [mL]	DWE [%]	σn-1
A	22.97	11.46	10.48	91.4	2.14
B	13.85	6.92	6.82	98.5	0.608
C	17.30	8.64	8.51	98.4	0.643
D	22.73	11.34	11.18	98.6	0.493
E	23.62	11.83	11.50	97.2	0.330
F	37.54	18.79	13.38	71.3	1.56
G	10.85	5.43	5.08	93.5	0.766
H	12.71	6.35	5.77	90.8	2.23
I	22.83	11.41	10.73	94.1	1.34
J	12.40	6.20	6.06	97.7	0.268
K	19.76	9.86	8.10	82.1	6.14

If bursting strength is a concern, one can choose from a broad selection, ranging from knit or woven fabrics which did not break on the diaphragm tester, down to fabrics constructed by papermaking or spunbonding technologies. The best combination of good "wipe-dry" and high strength were claimed, once again, by the bulky hydroentangled fabrics ("D" and "C").

Also included in *Table 3* (and *Table 4*) are statistics of variability, expressed as σn-1, for the six replicates per item. In general, wipers with poor DWE's also turned in higher variability in picking up the challenge, while those with high DWE's performed more consistently. A linear correlation of DWE with σn-1 gave a correlation coefficient, "r," of –0.80. A similar correlation, this time between DWE's and the underlying rate of sorption (R_e) from *Table 2*, indicated a somewhat poorer dependency, with an "r" factor of +0.60. While rate of sorption is an important factor in influencing wipe-dry, it does not tell the whole story. As indicated earlier, wiping efficiency is a complex issue involving not only the rate of sorption and capacity, but surface tension competition between the surface and the wiper for the fluid, and liquid de-sorption under the stresses of wiping.

In *Table 4*, data for DWE are given versus the challenge calculated on a relative basis. Here, each wiper was challenged with 50% of its statically-determined capacity. From the point of view of developing new wiping materials or in trying to compare wipers of very different capacities, expressing the challenge as a percent of the sorptive capacity of the wiper (100 v_c/A_{ip}) is more relevant.

For these data, the correlation between DWE and σn-1 is even stronger, if the outlier of the hydroentangled 82% rayon/18% polyester fabric ("F") is excluded. These data reflect a correlation coefficient of –0.96 for the relationship. Much of the high variability of wiper performance for those with low DWE (poor wipe-dry) is due to the visible trails of liquid left in their wake, akin to a barge pushing water aside as a bow wave.

One would expect as the 50% capacity challenge exceeded the constant volume challenge of 10 mL, the corresponding DWE's for the respective wipers would decrease. And, conversely, as the 50% capacity challenge represented less than the 10 mL constant volume challenge, the corresponding DWE's would increase. This, in fact, is born out by six of the 11candidates, with three additional items turning in about equivalent performance for each of the challenges. The remaining two, with odd performance, were composed of 100% polyester ("H") or 100% polypropylene ("K"). Whether this behavior is tied to their construction, composition, or merely the result of high variability (both had low DWE's) is unknown.

Key Words
Wiping Efficiency, Liquid Removal, Wipers

Conclusions
A new test to determine the dynamic wiping efficiency of fabrics was developed and applied to a range of wiping fabrics used in industrial, food service, and cleanroom applications. The dynamic test more nearly represents typical manual wiping than do static tests measuring sorbent capacity and rate. Eleven fabrics, representing a broad range of composition and construction, were assessed. As a class, hydroentangled fabrics generally outperformed those made by other means. Of those, fabrics with bulky character, imparted through creping or stitchbonding, exhibited superior "wipe-dry."

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TABLES

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Critical Evaluation of Upward Wicking Tests

By Bernard Miller, TRI, Princeton, NJ

Introduction
It has been and still is common practice to use in-plane wicking measurements to evaluate the absorbing power or liquid transport capabilities of fibrous sheet materials [1, 2, 3, 4]. Most versions of test methods used for this purpose start out by dipping one end of a sheet into liquid and monitoring the subsequent upward movement into the sheet, either by following the position of the liquid front or by gravimetric or volumetric changes. If the upward distance traveled by the liquid becomes long enough (in many cases, more than a few centimeters), there can be a noticeable effect of gravity on the flow rate. The ultimate effect, of course, will be when the liquid stops moving completely. At that point, the capillary pressure that raises the liquid is balanced by the effect of gravity, that is, by the weight of raised liquid.

Most testing procedures that are based on upward wicking either ignore the effect of gravity or implicitly assume that it will have a similar proportional influence on all materials. This report will demonstrate that such procedures can lead to misleading results and conclusions.

In addition, it is not generally acknowledged that, with a significantly volatile liquid such as water, evaporation from the wet surface of the sheet can compete with the capillary process that advances the liquid front. This competition can inhibit upward movement and net uptake and will have an increasing influence as wicking proceeds. In order to obtain reproducible and useful test data, it is necessary to carry out water wicking tests in a pre-saturated enclosed environment, or else use a less volatile liquid.

Liquid Movement Analysis
When the direction of movement is upward (i.e., against gravity), the capillary pressure P_c that drives the process is opposed by a continuously increasing hydrostatic pressure P_h, which is proportional to the height of the rise. In addition, movement is opposed by viscous drag, which also increases as the length L of the liquid column increases. These conditions can be described by using a form of the Poiseuille equation (a.k.a. Darcy's Law) for the velocity of a fluid with viscosity h moving through a porous network having an effective mean cross-sectional area K (i.e., its permeability):

$$\frac{dL}{dt} = \frac{K}{\eta L}(P_c - P_h) \quad [1]$$

We can express the pressures in terms of liquid rise: $P_c = L_c \rho g$ and $P_h = L\rho g$, where L_c is the height of the liquid column that would produce the equivalent of the capillary pressure, L is the height of rise at any time, ρ is the liquid density, and g is the gravitational constant.

Thus the flow velocity can be expressed in the form

$$\frac{dL}{dt} = \frac{\rho g K}{\eta}\left[\frac{L_c - L}{L}\right] \qquad [2]$$

Equation 2, after integration between L = 0 and L = L, becomes

$$L_c \ln\left[\frac{L_c}{L_c - L}\right] - L = \frac{\rho g K}{\eta} t \qquad [3]$$

Equation 3, describing linear motion, can be converted so that it describes uptake volume (if we assume complete filling of pores) by making the following substitutions:

$$V_c = L_c A \varepsilon, \text{ and } V = L A \varepsilon, \qquad [4]$$

Where A is the cross-sectional area normal to the direction of flow, and e is the porosity of the material. This produces

$$V_c \ln\left[\frac{V_c}{V_c - V}\right] - V = \frac{\varepsilon A \rho g}{\eta} K t \qquad [5]$$

Since the complimentary expressions for weight uptake would be $W_c = V_c\rho$ and $W = V\rho$, therefore

$$W_c \ln\left[\frac{W_c}{W_c - W}\right] - W = \frac{\varepsilon A \rho^2 g}{\eta} K t \qquad [6]$$

Using typical values for viscosity, density, etc., one can use Equations 3, 5, or 6 to predict the movements of a strongly absorbed liquid (L_c = 100 cm) and one that is absorbed less (L_c = 10 cm) into the same porous network. The results are shown in *Figure 1*. As can be seen, the rates of rise drop off precipitously and continuously shortly after the start of liquid movement. For both cases, velocity drops to about 10% of the initial value after a rise of about 5 cm.

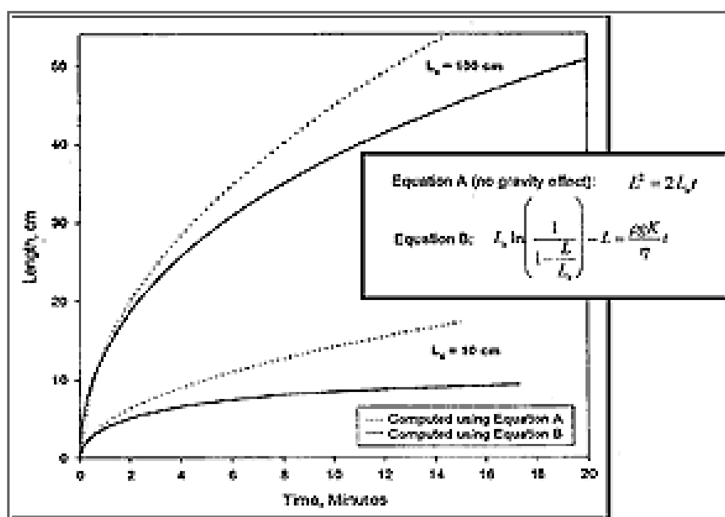


Figure 1
PROGRESS OF WICKING FOR STRONG AND WEAK ABSORBING SHEETS HAVING SAME CONSTRUCTION

In contrast, if the same materials were wicking in a gravity-free environment, the flows would be as shown by the broken lines in *Figure 1.* As would be expected, the less the capillary pressure, the more relatively drastic is the effect of gravity.

The curves shown in *Figure 1* clearly indicate that comparisons between the two materials made after an arbitrarily chosen singular time interval (or at a single height of rise) will not be reliable indicators of absorption performance. For example, the difference in distance traveled after two minutes is markedly less than that after 10 minutes, both in absolute and relative terms.

The previous analysis compared wicking rates for materials with different capillary pressures, but still having the same physical structure (i.e., permeability). However, when porous networks contain different distributions of pore sizes, such geometric differences can influence the movement of liquid even if the solid surfaces have the same wettability.

To obtain an expression for capillary pressure-induced flow in a single pore, we start with Poiseuille's Law for viscous flow through a single circular channel:

$$\frac{dV}{dt} = \frac{\pi R^4}{8\eta L}\Delta P, \qquad [7]$$

converting it to a linear flow rate,

$$\frac{dL}{dt} = \frac{R^2}{8\eta L}\Delta P, \qquad [8]$$

and combining it with the LaPlace expression for capillary pressure,

$$\Delta P_c = \frac{2\gamma}{R}, \qquad [9]$$

leads to

$$\frac{dL}{dt} = \frac{\gamma R}{4\eta L} \qquad [10]$$

This is one form of what is often called the Washburn equation, assuming complete wettability, that is, contact angle = zero.

Integration between L = 0 and L produces

$$L^2 = \frac{\gamma R}{2\eta}t \qquad [11]$$

According to this, we would expect liquid always to flow faster through a larger pore. However, the analysis above does not account for the influence of gravity when the wicking process is vertical upward. As previously explained, the rate equation should now include an opposing hydrostatic pressure ΔP_H:

$$\frac{dL}{dt} = \frac{R^2}{8\eta L}\left(\frac{2\gamma}{R} - \Delta P_H\right) \qquad [12]$$

Since $\Delta P_H = \rho g L$, Equation 12 becomes

$$\frac{dL}{dt} = \frac{1}{\eta}\left(\frac{2\gamma R - \rho g R^2 L}{8L}\right) \qquad [13]$$

Rearranging and integrating produces

$$\frac{8L\,dL}{2\gamma R - \rho q R^2 L} = \frac{1}{\eta}dt$$

$$\frac{16\gamma R}{(\rho g R^2)^2}\ln\left[\frac{2\gamma}{2\gamma - \rho g R L}\right] - \frac{8L}{\rho g R^2} = \frac{1}{\eta}t \qquad [14]$$

In order to focus on the specific effect of pore size (radius R), we will assign the following constants, which are approximately correct for water:

= 70 dynes/cm

$g\rho = 10^3$ dynes/cc

and $\mu = 1.0$ centipoise.

These constants convert Equation 14 into

$$\frac{11.2}{10^6 R^3}\ln\left[\frac{140}{140-10^3 RL}\right]-\frac{0.08L}{10^3 R^2}=t \qquad [15]$$

For any particular pore radius, a specific L versus t relationship can be written. For example, if R = 0.01 cm,

$$11.2\ln\left[\frac{1.4}{1.4-0.1L}\right]-0.8L=t \qquad [16] .$$

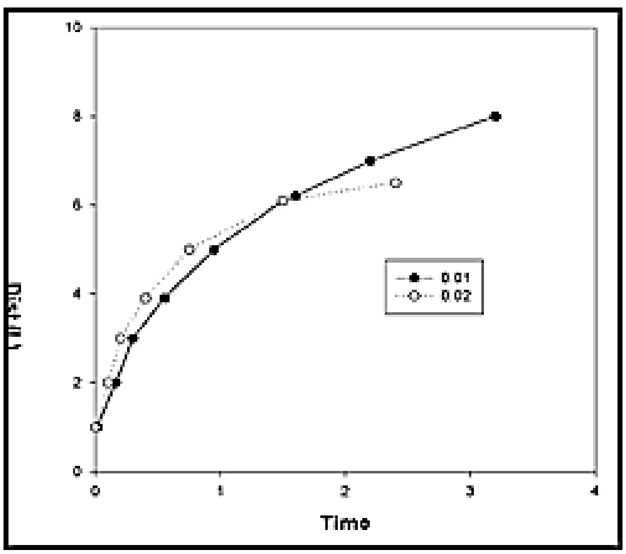


Figure 2
WICKING PROGRESS FOR TWO DIFFERENT SIZE PORES

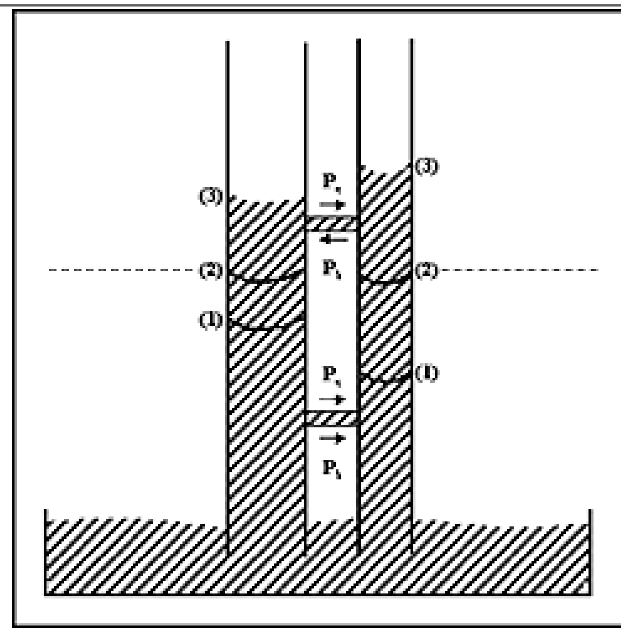


Figure 3
PREDICTED LIQUID TRANSFER BETWEEN TWO INTERCONNECTED PORES DURING WICKING

Therefore, we can compare competitive wicking for any collection of pore sizes, using the appropriate versions of Equation 15. *Figure 2* shows length versus time plots for two different pore sizes. At first, the larger pore moves liquid faster than the smaller one, but eventually, the flow rate in the former slows down more drastically, and at some point, while both pores are still moving liquid, the front in the smaller one passes the other.

The effect of this transition on the uniformity of the liquid front in an interconnected multipore system can be anticipated with the help of *Figure 3.* At time (1) the level in the larger pore, being higher, produces a hydrostatic pressure gradient P_h that will move liquid from the larger to the smaller. At the same time, the greater capillary pressure produced by the smaller pore will also pull liquid from the larger one.

The combined effect of these two processes will be to minimize any difference in liquid height within the pores. The rising liquid front of the multiporous material will be effectively uniform. At time (2) the fronts in the individual pores are at the same height and therefore there is no hydrostatic transfer effect. The difference in capillary pressures will still cause movement of liquid from the large to the smaller. At time (3) (and from then on) the capillary pressure will still be transferring liquid from the larger pore and will thus be augmenting the more rapid advancement of the liquid in the smaller pore. The hydrostatic pressure difference will now be opposing this nonuniform rise.

Thus one would expect the liquid front in a network containing large and small pores to be effectively uniform during the early stages of upward wicking, but then to become progressively disperse as the liquid in the smaller pores moves ahead of that in the larger ones. This phenomenon has been observed with many such systems.

Figure 4A
WICKING RACE BETWEEN SAMPLES A AND B

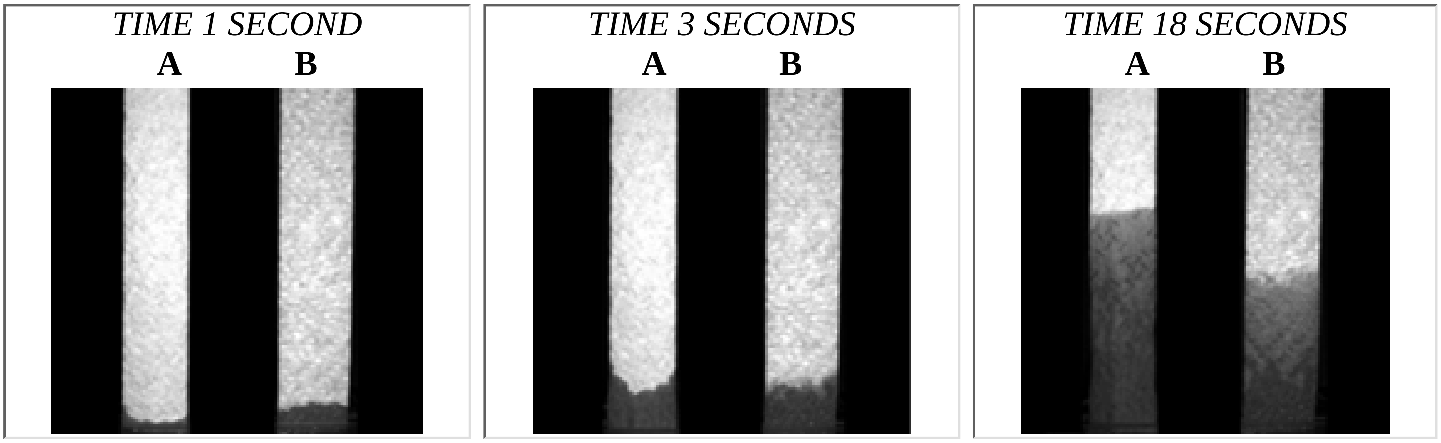
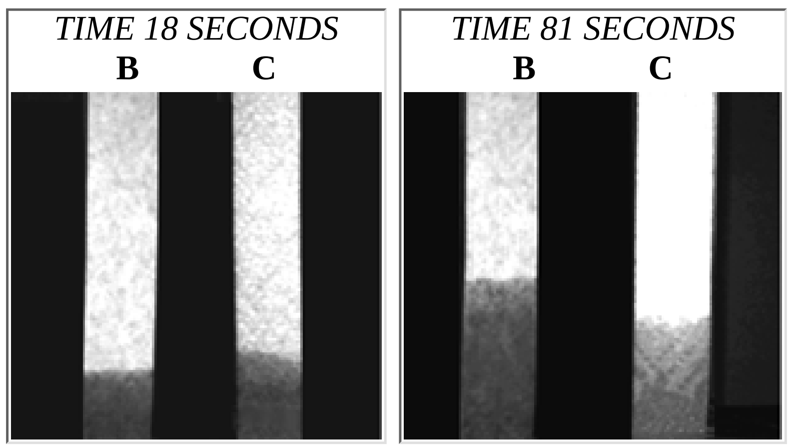
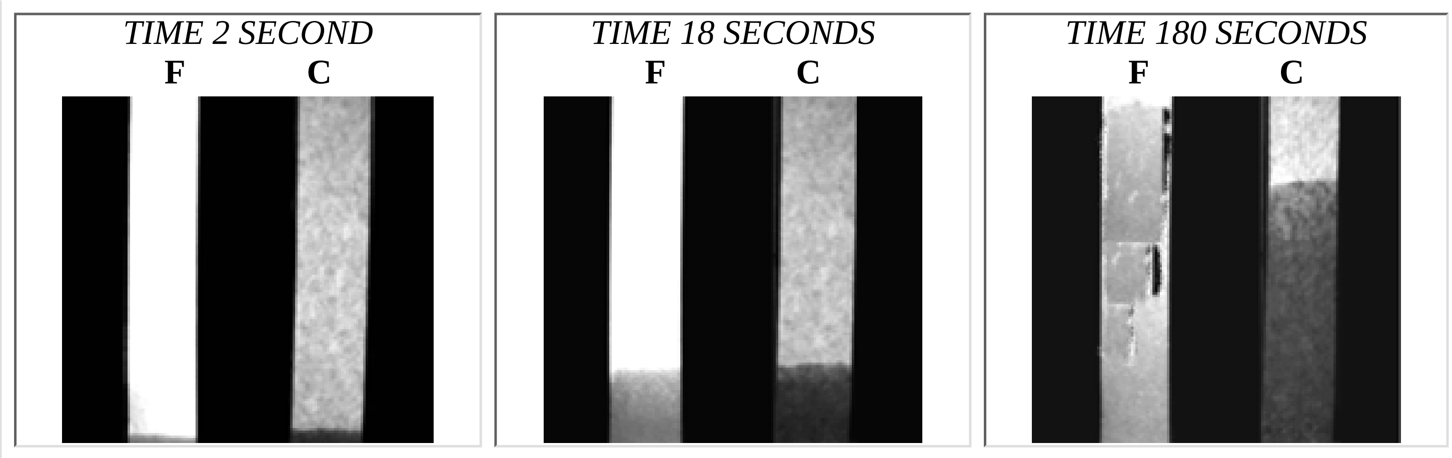


Figure 4B
WICKING RACE BETWEEN SAMPLES B AND C



Competitive wicking studies with a set of household paper towels (labeled A, B, C) and a laboratory grade filter paper (F) have been carried out with the aid of digital camera recordings at one second intervals. The pictures shown in *Figure 4* clearly show that the "overtaking" phenomenon does occur with such materials. In 4a it can be seen that the rise of liquid is initially faster in Sample B, however, within a few seconds and after a rise of about 2 centimeters, the wicking rate for Sample A becomes greater. The next set of pictures, (4b) shows a similar effect when Sample B and C are compared. The rise in C, which was first slower that that in B, becomes faster after about two minutes. The third set (4c) also illustrates the same transformation as the wicking rate in the filter paper overtakes that in Sample C.

Figure 4C
WICKING RACE BETWEEN SAMPLES F AND C



All of the results shown in *Figure 4* are consistent with the general principle that smaller pore will start out wicking upward at a slower rate but will eventually move liquid faster. The pore size distributions for the four samples, obtained by incremental pore volume distribution analysis [5], as shown in *Figure 5,* affirm this dictum.

This "overtaking" phenomenon, as predicted by analysis and demonstrated by the pictures shown in *Figure 4*, clearly inform us that, especially when competing materials have different pore sizes, an upward wicking test procedure will not be able to identify which is the fastest absorber. Each of the four candidates used in that study was the "fastest" at some point in time or distance.

Downward Wicking
One approach to a rigorous test for wicking performance that appears to avoid the above problems is to monitor downward wicking.

In practice, downward wicking experiments could not be performed without some initial upward wicking phase. One kind of experimental arrangement is shown in *Figure 6*. For this case, the hydrostatic head at any time should be

$$P_h = \rho g(L_o \cos\beta - L) \quad [17]$$

Substitution of this into Equation 1, keeping in mind that the total flow length is $L_0 + L$, leads to

$$\frac{dL}{dt} = \frac{\rho g K}{\eta}\left(\frac{L_c - L_0 \cos\beta + L}{L_0 + L}\right) \quad [18]$$

It is helpful to define a single constant

$$C = L_c \cos\beta \quad [19]$$

This produces

$$\frac{dL}{dt} = \frac{\rho g K}{\eta}\left[\frac{C + L}{L_0 + L}\right] \quad [20]$$

(Here L is the length of the liquid front starting from the beginning of downward movement.)

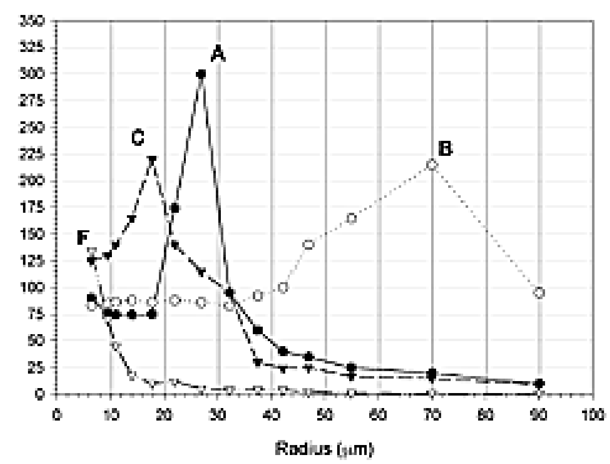


Figure 5
PORE SIZE DISTRIBUTIONS OF THE SAMPLES USED FOR COMPARATIVE WICKING STUDIES

When integrated between L = L and L = 0, the above becomes (with time t starting at the moment when downward flow begins)

$$(L_0 - C)\ln\left[\frac{C+L}{C}\right] = \frac{\rho g K}{\eta} t \qquad [21]$$

Comparing Equation 20 for downward wicking with Equation 3 for the upward direction, one sees that they have somewhat different forms. An example of the progress of downward wicking, as predicted by Equation 20, is shown in *Figure 7.* After an initial deceleration, the rate of wicking becomes essentially constant. This can be explained by the following:

The general equation for downward wicking can be used to predict the consequences of certain experimental conditions. For example,

when $L_0 = L$

$$\frac{dL}{dt} = \frac{\rho g K}{\eta}\left[\frac{C + L_0}{2L_0}\right] \qquad [22]$$

when $L_c >> L_0 = L$

$$\frac{dL}{dt} = \frac{\rho g K}{\eta}\left[\frac{L_c}{2L_0}\right] \qquad [23]$$

when $L_c \sim L_0 \sim L$

$$\frac{dL}{dt} = \frac{\rho g K}{\eta}\left[\frac{L_0 - \sin\beta L_0}{2L_0}\right] \qquad [24]$$

These relationships are useful because they equate an easily measured flow rate to a set of material and experimental constants. Since, at this point the movement of the front is relatively slow, L is not changing significantly, and, therefore, the flow rate remains steady, as shown in *Figure 7*.

The condition $L_0 = L$ that leads to a "constant" flow rate can then be used to determine the two fundamental quantities that control the wicking process, namely, capillary pressure P_c and permeability K. If we carry out two experiments with the same specimen, changing only the L_0 distance, we will get a different constant flow rate for each run. (Referring to *Figure 6*, this is done simply by moving the roller bar to a different position.) The ratio of these two rates can then be used in the following relationship:

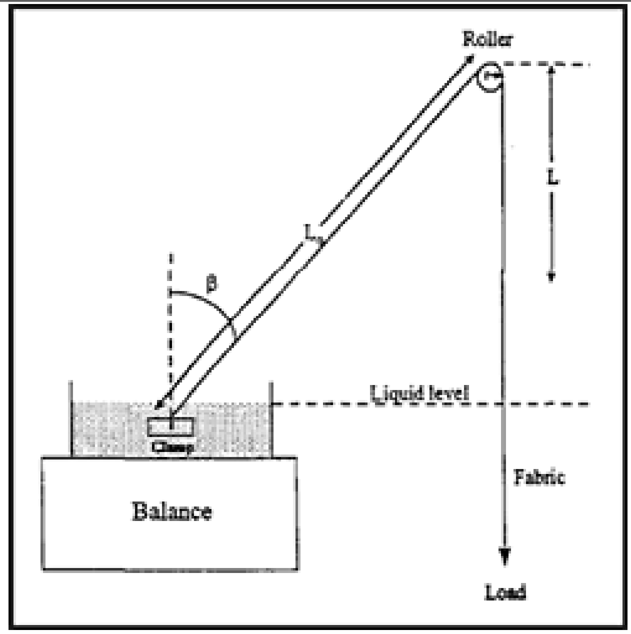


Figure 6
ARRANGEMENT FOR CARRYING OUT CONTROLLED DOWNWARD WICKING TESTS

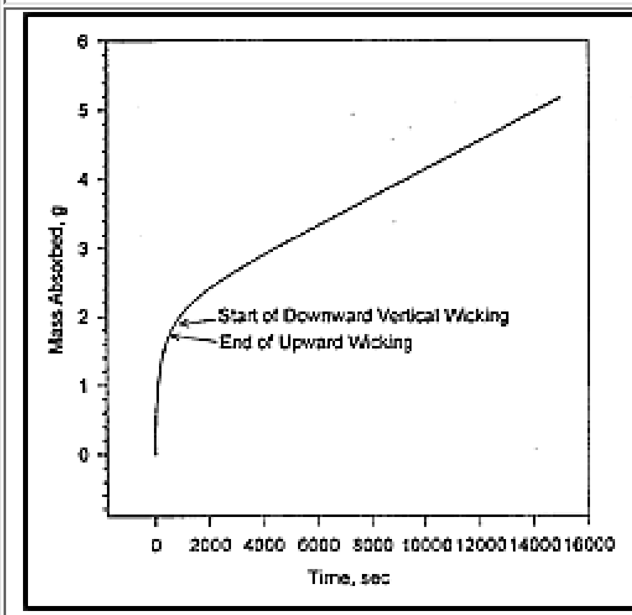


Figure 7
RESULTS OF DOWNWARD WICKING TEST (LIQUID USED WAS HEXADECANE)

General expression for downward wicking when $L_0 = L$

$$\frac{dL}{dt} = \frac{\rho g K}{2\eta}\left[\frac{L_c}{L_0} + 1 - \cos\beta\right] \qquad [25]$$

Ratio (f) for two flow rates

$$f = \left[\frac{dL}{dt}\right]_1 \Big/ \left[\frac{dL}{dt}\right]_2 = \left(\frac{L_c}{L_{01}} + 1 - \cos\beta\right) \Big/ \left(\frac{L_c}{L_{02}} + 1 - \cos\beta\right) \quad [26]$$

$$f\left(\frac{L_c}{L_{02}}\right) - \frac{L_c}{L_{01}} = (f-1)(\cos\beta - 1) \quad [27]$$

$$L_c = \frac{(f-1)(\cos\beta - 1)}{f L_{01} - L_{02}}(L_{02}L_{01}) \quad [28]$$

Once L_c is determined, it can be entered into the general equation 25 and used with either flow rate to obtain the permeability:

$$K = \frac{2\eta L_0}{\rho g}\left(\frac{1}{L_c - L_0\cos\beta + L_0}\right)\frac{dL}{dt} \quad [29]$$

In this way we can determine the capillary height (L_c), and therefore, the capillary pressure (P_c), and the permeability K. With these two fundamental properties, one can predict the overall wicking performance of a material under any conditions.

Conclusions

The theoretical and experimental evidence presented here clearly suggest that upward wicking testS that are based on a single endpoint, either of time or distance, may produce comparisons that will be misleading. The downward wicking arrangement and analysis seems to be one way to obtain useful information in a reliable and practical manner.

— ***INJ***

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Industry Meeting Review

The Third Nonwovens Symposium
2000 Cotton Beltwide Conferences

The Third Nonwovens Symposium was held under the auspices of the 2000 Beltwide Cotton Conferences in sunny San Antonio, TX on January 7, 2000. The Beltwide Cotton Conferences had a registration of 4,000; the group was comprised of cotton growers, processors, researchers, users, buyers, sellers, chemical suppliers and a wide variety of other specialists interested in cotton. The nonwovens symposium featured seven invited speakers and four poster presentations.

Dr. Jerry Morton of Buckeye Cellulose chaired the first session and Robert Briggs, Director of Wyant Corporation, and of Paper-Pak Products, Inc. chaired the second session. Drs. D.V. Parikh, T.A. Calamari, and the SRRC Director, Dr. John Patrick Jordan, opened the Nonwovens Symposium. In the welcome it was pointed out that nonwovens were the fastest growing segment of textiles and that the last three decades of the past century had seen the dominance of the U.S. in nonwovens research and manufacturing. Six billion people are standing at the gate of this millennium; the nonwovens participants were challenged to develop products that would make lives of six billion more comfortable.

Dr. Edward Vaughn, Professor, School of Textiles, Clemson University gave the keynote address, entitled, “Nonwoven Hybrids – The Route to Millennium Magic.” Hybrids cause synergism (unexpectedly greater than the sum of all the parts) and create products that never existed before. Essentially, nonwoven technologies adapt machinery and processing principles that are traditionally used in the textile, paper, and extruded polymer industries along with those of air-laid technology to produce rolls of nonwoven fabrics at high speed. Nonwoven hybrids incorporate the advantages of two or more nonwoven manufacturing systems while eliminating the weakness to produce specialized fabrics with properties unattainable by any single nonwoven process.

Dr. Vaughn summarized that the nonwoven hybrid structures are the product of industrial creativity and invention and have been made possible through the development of understanding of specific technical needs and the intelligent selection of materials and processes to most efficiently satisfy those needs. They have been proven to be successful because they perform better than other fabrics and often provide properties and performance levels not approachable by other fabrics.

- Mr. Bill Goynes of SRRC presented data on needlepunched blankets made from low-grade gray cotton and recycled polyester.
- Steven Vandal, Vice President, Paper-Pak Products, Inc. presented a paper, "The Fiberization Process in Incontinence Production."
- Frank Dueck of Hollingsworth on Wheels discussed carding of cotton for nonwovens market.
- Dr. Bhupen Gupta of N.C. State University presented fluid imbibition of nonwovens containing cellulose acetate.
- Vera Soukupova and Dr. David Lukas presented “Sorption Kinetics and Capacity of Perpendicular-Laid Highloft Cotton Fabrics,” an outcome of FAS-USDA (Foreign Agricultural Service, U.S. Department of Agriculture) research grant awarded to the Technical University of Liberec, Czech Republic.
- Mac McLean of Cotton Incorporated presented “Cotton in Absorbent Core.”
- The following four papers were presented in the poster session:
  1. Cotton/Polyester Nonwoven Blend With Antibacterial Activity, T.L Vigo, D. V. Parikh, and G. F. D’anna, SRRC, USDA.
  2. Preparation of Kenaf Fibers For Processing into Automotive Nonwovens, D.V. Parikh, T.A. Calamari and A.P.S. Sawhney, SRRC, USDA, and Mary Warnack, University of Arkansas
  3. The Fine Structure of Chemically Modified Cottons, D.V. Parikh and D. P. Thibodeaux; SRRC, USDA.
  4. Naturally Colored Brown Cotton For Needlepunched Nonwoven Fabrics, Linda Kimmel, Weiying Tao and Valeriy Yachmenev, SRRC, USDA. — *D.V. Parikh and T.A. Calamari, SRRC, USDA, New Orleans, LA*

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