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THERMALLY BONDED LAMINATES OF NOVEL BINDER FIBER MATERIALS WITH NATURAL FIBERS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Nataraj Gosavi

May 1992

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DEDICATION

This thesis is dedicated to my parents, Mr and Mrs. G. Jagannath Bhatt for their extraordinary patience and support during my student days.

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ABSTRACT

Laminates of cotton and/or ramie and thermally fusible binder fiber materials have been developed for applications such as hospital operating room fabrics, diapers, and feminine hygiene products to take advantage of the good strength and comfort properties of cellulosic fibers and also the fact that these are biodegradable fibers. The development of laminates takes three important parameters into consideration: precursor web parameters, staple fiber web parameters, and thermal bonding process parameters. Samples were made using combinations of the three parameters. The samples were tested for properties desired in the resultant laminates. The primary objective of Part A of this study was to take different ratios of cotton and synthetic fibers along with melt blown webs as the outer layers to produce fabrics for medical apparel having a range of strength and barrier properties. Repellency characteristics of the laminates were improved by applying a fluorochemical finish. The weight of the precursor melt blown webs, and top and bottom roll temperatures appeared to have a notable effect on the barrier and strength properties of the laminates. The fluorochemical finish was found to further enhance the barrier and repellency properties. The Wilcoxon Signed Rank statistical analysis technique was used to determine if the difference in was significant at the 0.05 level properties between unfinished and finished laminates.

The objectives of Part B of this study were to develop laminates from combinations of natural fibers with melt blown and/or spunbond webs as the outer layers and to characterize their water wicking, absorbency and retention capacities. Cotton and ramie were utilized in the core to take advantage of the excellent wicking and absorbency of these fibers as well as the fact that they are

renewable and biodegradable fibers for such applications as personal hygiene products, baby and adult diapers, and incontinent pads. The weight of the staple fiber and precursor webs and the type of the precursor webs were found to have notable effects on the absorbency and strength properties of the laminates. Spunbond fabrics were found to enhance the strength of the laminates as well as the absorbency by providing a more open structure compared to melt blown webs.

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CHAPTER 1

INTRODUCTION

Nonwoven fabrics have found acceptance in the medical industry as disposable substitutes for the reusable cotton examination gowns, surgical gowns, surgical drapes, face masks, shoe covers, sterilization wraps and other products, to the extent that this market for nonwoven products is estimated to exceed one billion dollars yearly. Further, nonwovens have found use in sanitary products, such as sanitary napkins, disposable diapers, incontinent pads, and other similar products. One of the benefits of nonwovens has been their relatively low cost, as compared to woven fabrics. The difference in cost between nonwoven and woven fabrics has in the past been of a magnitude such that the end users can dispose of the nonwoven web product after a single use and yet realize a monetary gain over the multi use woven fabrics.

The properties of a nonwoven required for use in medical apparel are the drapability, comfort, strength, and barrier properties of the web. Properties desired in personal hygiene products, bed pads, and diapers are wicking, absorbent capacity, retention capacity, and adequate wet strength of the product. Also of importance in acceptance of the nonwoven by the end user is the degree to which it approximates the desirable properties of a woven fabric. Nonwoven fabrics may be engineered to meet these end uses; however the hand and strength of woven fabrics are more difficult to attain. This study attempts to improve these properties of nonwovens through developing new products based on natural fibers such as cotton and ramie.

The present study has been divided into two parts, Part A and Part B. The objectives of the present study are as follows:

Part A: Barrier properties of MSM laminates

To develop medical protective apparel from Melt Blown/Staple Fiber/ Melt Blown (MSM) laminates and to characterize the barrier, strength, and drapability properties of different weights and compositions of MSM laminates.

Part B: Absorbency properties of laminates

To develop laminate fabrics of natural cellulosic fibers with melt blown webs, spunbond webs or combination of melt blown and spunbond webs as the outer layers in order to better develop for personal hygiene products, incontinent pads, and diaper applications and to characterize the absorbency and strength properties of different weights and compositions of the laminates.

CHAPTER 2

LITERATURE REVIEW

Nonwovens

Nonwoven fabrics are defined [1] by the INDA (Association of the Nonwovens Fabrics Industry) as "sheet or web structures made by bonding and/or interlocking fibers, yarns or filaments by mechanical, thermal, chemical or solvent means". These fabrics do not require the conversion of fibers to yarn. Nonwoven fabrics are manufactured by processes other than spinning, weaving, or knitting, hence the name 'nonwovens'.

The basic structure of all nonwovens is a web of fibers or filaments. Thus, a single fiber or filament may be the basic element of all nonwovens. In nonwovens, the individual fibers may be in uniaxial or random arrangement. Tensile strength, tensile elongation, and hand properties are imparted to the web by the type of bonding as well as fiber-to-fiber cohesion and reinforcement by its constituents.

The technology for making nonwoven fabrics is based on the following primary elements: fibers of various lengths and diameters; a web arranged according to the method of forming and processing; the bonding of fibers within the web and reinforcement by its constituents. The variation of one or several elements in combination allows for the enormous range of nonwoven fiber types [2]. Control of the type and length of the fibers and of the bonding, in combination with the selection of the manufacturing method, gives rise to a highly technical, yet extremely flexible combination of options. This flexibility means that products

can be designed in a wide range of products to the specific requirements of the end user .

Since 1942, the first time [2] these fabrics were referred to as 'nonwovens', nonwovens have come a long way because of new forming and bonding techniques. Improvements and advances in synthetic fibers and additives combined with process research and machine development have paved the way to new, innovative, and very important nonwoven products. These developments in the nonwoven industry have led to new fabric structures having valuable and, more importantly, marketable properties.

Nonwovens are also referred to as engineered fabrics, because they provide specific functions for specific end uses. By engineering nonwovens, the nonwoven industry has the means at its disposal to achieve superior performance properties, satisfy consumer and societal needs, make major inroads into the woven/knit fabric domain, and go well beyond these domains. The clever and systematic usage of these means will go a long way in improving nonwoven properties which are deficient, thereby promoting the interests of the nonwoven industry.

Medical Nonwovens

Disposable nonwovens entered the medical field nearly three decades ago, beginning with basic, paper-like face masks and proceeding through sterilization wrap and specialty drapes to become close to a $2 billion market. These medical nonwovens have proved to be invaluable in products ranging from drape sheets to surgical gowns to adult pads and underpads by utilizing a gamut of nonwoven processes. The combining of nonwoven technologies has enabled

the industry to offer products with properties hitherto thought impossible.

Medical nonwovens [3] have moved from a phase of reluctance to a phase in which hospital personnel trust them with no reservation whatsoever. Initial reluctance was due to the following reasons:

- A lack of knowledge of nonwovens and lack of information - regarding their manufacture, structure, quality, and range - from manufacturers to consumers.
- Very average quality of the product.
- Problems in adapting a material that came in a very small range to the multitude of surgical situations.
- Reluctance on the part of the hospital personnel to adopt to a new product and on the part of hospital administrators to accept potentially more expensive disposable products.

Sufficient and pertinent information of nonwovens provided by the manufacturers, improvement of the quality of nonwovens, development of nonwovens for almost every situation, and nonwovens proving their efficiency as effective barriers for bacterial penetration have been the reasons for hospital personnel and administrators placing complete trust in nonwovens. Thus, they have become convinced that they are choosing a proven product that can be rationally used. Besides being effective against bacteria and airborne contamination, most of the nonwovens are also lint-free and have contributed to the feeling that nonwovens are more reliable materials that reduce post-operative complications to a considerable extent. Other advantages of nonwovens include: a sterilized form, ready to use but easy to store, a fixed price, and disposability [3].

By virtue of having specific products for specific end uses, the nonwovens [3] have facilitated greater convenience in storage and identification, leading to savings benefits in equipment, labor, and inventory. Further savings are provided by the energy that may be recycled from incineration. Forecasting of needs is

also improved since it is simpler to monitor used products. Another prime advantage by the use of nonwovens is the improvement in working conditions for operating room staff.

Nonwovens [4] now have almost complete acceptance in the United States. hospitals for applications such as surgical caps, masks, and shoe covers; 90-100% penetration in operating room usage has resulted because nonwovens provide relatively inexpensive, light-weight, and effective protection. Nonwovens seem to be having an equal footing with wovens in uses such as surgical gowns and drapes, wherein they have about 50-60% share of the market. With the majority of the medical community being convinced that nonwoven disposables give double benefits of superior barrier protection and ease-of-use, it is only the psychological barrier that needs to be overcome before nonwovens achieve 75-80% penetration in the operating room market.

Properties desired in operating room fabrics

AORN (Association of Operating Room Nurses) specifies [5] that "surgical drapes and gowns should be of material that can establish an effective barrier eliminating the passage of microorganisms between sterile and nonsterile areas".

"Criteria to be met in establishing an effective barrier [5] are:

- Blood and aqueous fluid resistant
- Abrasion resistant to eliminate bacterial penetration
- Lint free to reduce the number of particles in the air.

Additional criteria that must be considered in determining which draping materials to use include:

- The requirements of the National Fire Protection Association so there is no risk of a spark from static charge
- Sufficiently porous to eliminate heat buildup
- Drapability."

Absorbent Products

Many healthcare and personal hygiene products need to control liquid flow [6], both in terms of capacity and rate factors, which will be appropriate for a specific end use. This control of liquid flow can be achieved by incorporating effective capillary systems into the end product. Cellulosic fibers are particularly capable of providing the capillary systems necessary for these products. Among the cellulosic fibers used in absorbent products, only pulp and cotton are used to a great extent. Wood pulp is effective in single or in composite structures. But it has the disadvantage of having short fibers compared to cotton. In addition the pulp fibers are not suited for being processed on textile carding equipment. Although pulp fibers may be processed by air-laid or wet-laid methods and subsequently mechanically or adhesively bonded, the structures are generally weak and paper-like due to the short fibers. In contrast the long cotton fibers result in fabrics with greater strength since fewer bonding points per fiber are required to stabilize the structure. This makes cotton an ideal choice, especially for processing on textile equipment. Furthermore, cotton offers properties that are most suitable for constructing effective capillary control in absorbent nonwoven healthcare and personal hygiene products. Internal microscopic pore spaces of cotton contribute to its ability to swell during the transition from the dry to the wet state. This property is found to be advantageous in medical and personal hygiene applications.

Cotton fiber retains its gross capillary advantages [6] because of its irregular cross-sectional shape and surface texture, even in its finest micronaire range. This property of cotton is found to be useful in two ways:

- Influence of gross capillarity on liquid absorbency of the product. By virtue of this property cotton has the capacity to absorb, store, and subsequently release water vapor.
- Medical products used for cleanliness and personal hygiene relate to internal and external capillarity of fibers, which is related to the above stated unique property of cotton.

The absorbency characteristics of a fabric surface are reflective of [7] :

- Volume of the surface accessible to a fluid.
- The way a fluid wets the surface (of the volume that is accessible to it) and gets retained therein.
- The resistance offered by the surface to the removal of fluid from that volume.

The volume accessible to a fluid within a surface is called the *'absorbent capacity'* of the absorbent. The readiness with which the liquid is transported within the volume (in an absorbent fabric), vertically into the fabric web and horizontally within a plane of the fabric is called the *'wicking capacity'* of the absorbent. The resistance offered by the surface to the removal of fluid from that volume is called its *'retention capacity'* of the absorbent. Retention is a measure of "how well voids comprising the volume resist flow outward when exposed to desorbing influences of pressure, vacuum, and adjacent absorbing structures" [7].

Fibers used in Nonwovens

The single fiber or filament is seen as a basic element of all nonwovens. Fiber requirements for nonwovens depend on the product being produced and

the process being used. Since each process leads to a different range of fabric properties, all available fibers cannot be used on all nonwoven processes [8].

With nonwovens successfully moving into more technical end uses the fiber requirements have also become more demanding with regard to the fiber properties so as to be suitable for those applications. The cooperation between fiber suppliers and fabric producers is now seen as an important criteria for more advancements to come about in nonwovens [8].

Fibers used more commonly in the present study are cotton and polypropylene, and they are discussed in greater detail.

Cotton

Cotton in nonwovens. Cotton is [9] making an entry into nonwoven applications which was hitherto unfamiliar territory for it. With a very well established conventional textile market, the nonwovens field is seen to be an emerging growth area for the use of cotton. Its success in nonwovens is guaranteed because there are very few products making use of cotton and it has a great potential in end use markets such as medical/surgical products and sanitary products.

Cotton [9] by virtue of its unusual chemistry and structure offers a set of properties which are important to the performance of medical and healthcare products. These include high tensile strength, exceptional absorbency, highly efficient wicking, natural resistance to electrostatic charge build-up, and good processability. The unusual properties of cotton cannot be duplicated by synthetic fibers. Synthetic fibers constitute the bulk of fibers being used in medical and healthcare applications of nonwovens. The reason for this situation is that cotton

has not been available in a form that could be utilized economically by most nonwovens manufacturers. This is changing because of the new and innovative technology being introduced by Cotton Incorporated and cotton suppliers. Suppliers have improved the processability of cotton to meet the stringent requirements of nonwovens manufacturers not just by increasing the openness of the fiber, but also by improving types of finishes available, the application of finish, and the consistency of quality from lot to lot. All this is in addition to the unique properties of cotton. Improved processability has led to improved acceptance. This has made cotton extremely versatile in terms of processability and has made it possible to be used in most of the nonwoven processes, with only processes requiring thermoplasticity such as extrusion being exceptions.

Type of Cotton Used.Most of the cotton [9] used in nonwoven and disposable products is bleached and scoured. This is necessary to remove the natural coating of wax, pectins, and protein present on the primary wall of cotton fiber and to whiten the fiber.

The most common method of bleaching and scouring is the kier process. The cotton produced by this process is used in many absorbent medical and healthcare products.

An alternative to the kier process is Cotton Incorporated's continuous bleaching and scouring process. This presently appears to be the most cost and energy effective technology. This process produces a high quality cotton fiber, which is easy to process, and a very uniform fiber product. It allows the usage of cotton directly from the bale in most of the nonwoven processes.

Benefits of using cotton. Cotton [9] being a highly absorbent fiber, finds a host of applications in the medical and healthcare field such as bandages, absorbent pads, tampons, sponges, and other associated applications. The ionic nature of the liquid to be absorbed does not adversely affect the absorbency of cotton. Cotton can thus be used to absorb urine, saline solution, blood, and other body fluids in addition to being highly effective with non-aqueous fluids such as oils and oil based lotions.

Cotton [9] has excellent heat resistance and retains its dimensional stability when exposed to temperatures in excess of 300 °F. Due to this reason, sterilization procedures pose no problems for cotton. It can be sterilized using heat, ethylene oxide, or gamma radiation without any adverse effects on the products.

Many medical [9] uses require resistance to electrostatic build-up for reasons of safety. This necessitates the addition of an antistat to the fiber or finished product. By virtue of having an inherently low electrostatic charge potential, cotton does not need any antistat treatment. This property is not adversely affected by washing, desizing, or scouring techniques.

Cotton's unique morphology and structure [9] make it a naturally 'breathable' fiber and by which it is able to resist the passage of liquid while allowing the transpiration of water vapor and gases. This inherent capability of cotton makes it the ideal choice in applications like operating room gowns, where transpiration is desirable.

Cotton [9] when wet has a pleasant feel unlike the slick or greasy feel of some synthetic fibers. This is useful in healthcare applications requiring skin contact or handling by patients or hospital personnel. Cotton also has significant

wicking power. This gives cotton the ability to draw liquids away from a surface. This property is important in operating room and other related medical uses.

Polypropylene

Polypropylene (PP) is produced from polymers formed by chain growth polymerization of olefins and contain greater than 85% propylene [10].

Polypropylene is one of the most versatile of polymers. By virtue of its advantageous fiber - forming abilities, it is used in more fibrous forms than most polymers. Significant properties are listed below [11, 12]:

- Ability to be melt - spun and drawn
- Ability to be produced in a wide variety of fiber and textile related forms
- High strength and abrasion resistance
- Ability to be thermally bonded
- Advantage of low specific gravity leading to high covering power
- Excellent resistance to acids and alkalis
- Ability to be processed on most conventional textile equipment
- Attractive price/performance properties ratio

Polypropylene's versatility has resulted in it being used in spunlacing, needlepunching, thermal bonding, spunbonding, melt blowing, wet laying, and stitch bonding. It has also opened up areas where combination nonwovens can be made. These merits of polypropylene have led to it capturing a major market share and also resulting in it replacing other fibers used in the manufacture of nonwovens to a great extent.

Techniques for manufacturing nonwovens

Nonwovens are manufactured by processes that are different from one other in many ways. However, all the processes have web formation and web consolidation or bonding. By combining a variety of methods used for each step and by choosing from a wide range of fibers, nonwovens can be tailor made to suit its applications.

Web Forming.

This step is the creation of a loosely held together sheet structure, which is achieved by the laying down of fibers. Fiber length is the factor which determines the method that should be used to form webs. This step of web forming can be carried out by one of the three methods: wet laid, dry laid, and direct or polymer laid.

Web Bonding.

From most web forming processes, the web obtained is too weak to be used in that form. This necessitates the step of web bonding in order to provide consolidation of the web. This step gives the strength needed by the web. Bonding can be carried out by one of the three methods: chemical, mechanical, and thermal.

Melt Blowing. Melt blowing is a process in which a fiber forming thermoplastic polymer is extruded through a die containing small orifices. Convergent streams

of hot air from both sides of the die are used to rapidly attenuate the extruded polymer streams exiting from the die to form extremely fine diameter fibers. The attenuated fibers are then blown by high velocity air onto a collector screen to form melt blown webs having microfibers. The fibers in the melt blown webs are bonded together by a combination of entanglement and thermal bonding occurring due to the heat of extrusion and hot air used to attenuate the polymer stream as it exits the die [13,14].

Melt blown webs generally exhibit low to moderate tensile strength due to a lack of drawing of fibers. The melt blown webs display higher filtration efficiency - due to the extremely large fiber surface area - and barrier properties as compared to spunbond webs. The micropores due to the microfibers allows gas penetration useful in sterilization, and moisture vapor transmission, and for thermal comfort, and thus make melt blown webs useful in operating room apparel applications.

Spunbonding. The spunbonding process is defined [15] as follows: "It is a process in which usually a thermoplastic fiber forming polymer is extruded through a linear or circular spinneret. The extruded polymer streams are rapidly cooled and attenuated by air to form desired diameter filaments. The filaments are then laid down onto a conveyor belt to form a web. The web is then bonded to form a spunbonded web."

Spunbond fabrics have greater tensile and tear strength in both directions in comparison to staple fiber nonwovens. These fabrics are known to be the stiffest among nonwoven substrates. Very light weight spunbond fabrics can be used to compensate for stiffness [14].

Thermal Bonding. Thermal bonding [16] of nonwovens involves the use of heat energy to activate an adhesive process for the purpose of interlocking fibers and consequently consolidate or provide dimensional stability to fiber webs. Thermal bonding comes about through the combination of heating, flowing, and cooling of its components. The adhesive component is subjected to heat. As the adhesive approaches its melting point, its surface softens, and area of contact with more stable fibers expand to form potential bonding sites. Upon melting, the liquefied adhesive is attached to a network fiber, and flows along the network fiber to a crossing of two or more fibers. Once the nonwoven material is cooled, the adhesive solidifies and forms a bond or thermal fusion at each fiber contact.

In thermal bonding, fiber surfaces are fused to each other by melting the fiber surfaces or by melting fusible additives in the form of a powder, granules or fibers. Calendering is a method of bonding in which the web is pulled between heated rollers so that the web is exposed to heat and pressure necessary to bond the constituent fibers and layers together. The calender rolls [17] may be smooth or embossed, or a combination of both of them. Two smooth rolls lead to the bonding over the entire surface of the web. The end product is stiff and has poor drapability. The use of one embossed roll with a raised pattern (at the top) and one smooth roll (at the bottom) leads to only a portion of the web being exposed to the heat and pressure of rolls and only that portion is bonded. This is called as pattern or point bonding. The resultant product has good drape, hand, and strength.

The thermal bonding process has been widely accepted in the nonwovens industry because of its simplicity and its many advantages over traditional chemical bonding methods. Low raw material and energy costs, product versatility, lesser space requirements, cleanliness of the process, better product

quality characteristics, and increased production rates are the features that have been the reasons for its widely gained acceptance. Since the binder powders or fibers are mixed into the web, thermal bonding processes are rapidly adaptable to the manufacturing and designing of composite structures.

Repellent Finishing

Repellency can be described as a condition of limited wettability [18]. The nonwovens industry uses various finishes to achieve water, oil, and alcohol repellency. While these finishes do not generally affect the physical properties of the nonwovens, they do not provide the fabrics the ability to repel oil and low surface tension aqueous liquids [19]. The lack of repellency to oil and low surface tension aqueous liquids was seen as a significant deficiency in nonwovens made for the medical market where they encounter a variety of low surface tension liquids. Fluorochemical repellents were used to treat medical nonwovens in order to overcome the aforesaid deficiency.

Fluorochemical is a generic term used for a variety of organic fluorine - containing compounds where a majority of the hydrogen atoms are replaced by fluorine [19,20]. In perfluoro compounds, all the carbon - bonded hydrogen atoms in the parent radical are substituted with fluorine. In addition, perfluoro compounds contain a perfluoro - chain or ring that is affixed to a reactive group to enable further synthesis:

$$CF_3 - C_XF_{2X} - Z$$
(Perfluoro - Compound)

If 'Z' contains a polymerizable group, the perfluoro compound may be converted to a polymer and can be incorporated as polymeric systems which are usually aqueous dispersions or emulsions for ease of handling and applying [19]. Upon drying or curing on a fiber, the fluorochemical tails orient themselves away from the fiber thereby providing a low surface energy barrier. This offers resistance to wetting by most aqueous and non - aqueous fluids.

The repellency properties of fluorochemically finished substrates are related to the contact angle between the liquid touching the surface of the substrate and the surface tension of that surface. Zisman's equation is used to relate this property:

$$\text{Cos}\,\theta = 1 + M\,(\gamma_L - \gamma_C)$$

Where, θ = Contact angle between the liquid and the solid,
M = Constant,
γ_L = Surface tension of the liquid,
and γ_C = Critical surface tension of the solid.

From Zisman's equation, it is seen that as the surface tension of a liquid decreases, it induces a decrease in contact angle, and this leads to the solid surface being wet easily. A decrease in the critical surface tension of the solid leads to an increase in contact angle between the liquid and solid and thereby increases the resistance of the solid to wetting. Since fluorochemicals have a very low surface energy [18] they impart excellent repellency properties to nonwoven substrates.

Fluorochemical finishes are normally applied by conventional padding process. They are then dried and cured. Drying and curing is seen to be critical in order to develop optimum performance.

Fluorochemically treated hospital nonwovens provide the repellency needed to soaps, disinfectants, body fluids, and alcoholic solutions. By virtue of not being a film like deposition, i) they can be readily sterilized by the available techniques, and ii) they are sufficiently permeable in nature ensuring wearer comfort [19]. These advantages provided by the fluorochemically treated hospital nonwovens that also prevent the infection of the wound sites are readily welcomed by hospitals.

CHAPTER 3

EXPERIMENTAL DESIGN

Part A: Barrier properties of MSM laminates

Materials

For the melt blown fabric constituting the outer layers of the laminate, fabrics made of two 800 melt flow rate (MFR) PP resins - Himont Valtec 442 and Exxon Escorene Grade PD 3495G - were used. The one-meter wide melt blown webs were obtained from Reifenhauser, in Troisdorf, Germany. There were two fabric weights of 0.5 oz/yd^2 and 0.7 oz/yd^2 for each resin.

For the web constituting the middle layer of the laminate, bleached and precarded cotton (C) and polypropylene (PP) fibers were used either alone or as a mixture of both of them. The cotton used had the trade name of 'Easy Street', was "super-opened" for use in nonwovens, and was manufactured by Veratec. Two types of PP staple fibers were used. One of them was 'Hercules T-185', manufactured by Hercules Inc. The other was a BASF bicomponent fiber, 'Merge 1080'. The weight of the staple fiber web was kept constant at 1.0 oz/yd^2. From the recommendations of the preliminary study by Balasubramanian et al [21], C/PP blend levels of 100/0, 65/35, 50/50, and 0/100 were chosen. The last three compositions (65/35, 50/50, and 0/100) were chosen in order to determine if the presence of more binder fiber material in the blend would result in better bonding and increased strength of the laminate fabrics. In regards to fiber denier, one nominal cotton fiber denier (1.75) and two nominal PP fiber deniers (2.2 denier Hercules T-185 and 3.0 denier BASF bicomponent fiber Merge 1080) were

utilized. The specified length of the cotton fiber was 1.0 inch and the nominal length of both PP fiber types was 1.5 inch.

Process Description

A schematic diagram for the production of the nonwoven laminate is given in Fig. 1. For the preparation of the web, 100% cotton, 100% PP, blends of cotton and PP fibers were fed in the appropriate ratio by weight to the opener mixer. Here a uniform mixing of the constituent fibers occurs. Although one or more cards that primarily orient fibers in the machine direction (parallel - laid) may be used, it is preferable that the uniform mix from the opener be fed to a series of random laying cards, wherein web formation occurs. It is desirable that these cards be designed to produce or make as random of an orientation of fibers as possible. The web prepared at the card is fed onto a conveyor belt from the doffing roll. The melt blown fabrics, which form the upper and lower side of the laminate, are fed from the top and bottom side of the web moving on the conveyor belt. The cotton, C/PP, or PP web in a sandwiched configuration between the melt blown fabrics, is fed to the nip of the calender rolls. The calendering machine uses a combination of a patterned roll and a smooth roll. The patterned roll is usually found at the top and the smooth roll at the bottom. The surface geometry of the patterned roll used at the top influences the degree of bonding which in turn influences the properties of the resulting fabric. Only the area of the fabric beneath the raised embossed pattern is bonded as a result of the heat and pressure between the patterned and smooth roll from the heated contacts. Two smooth rolls would allow bonding of the entire fabric surface, but the fabric would be much stiffer. An optimum combination of pressure and

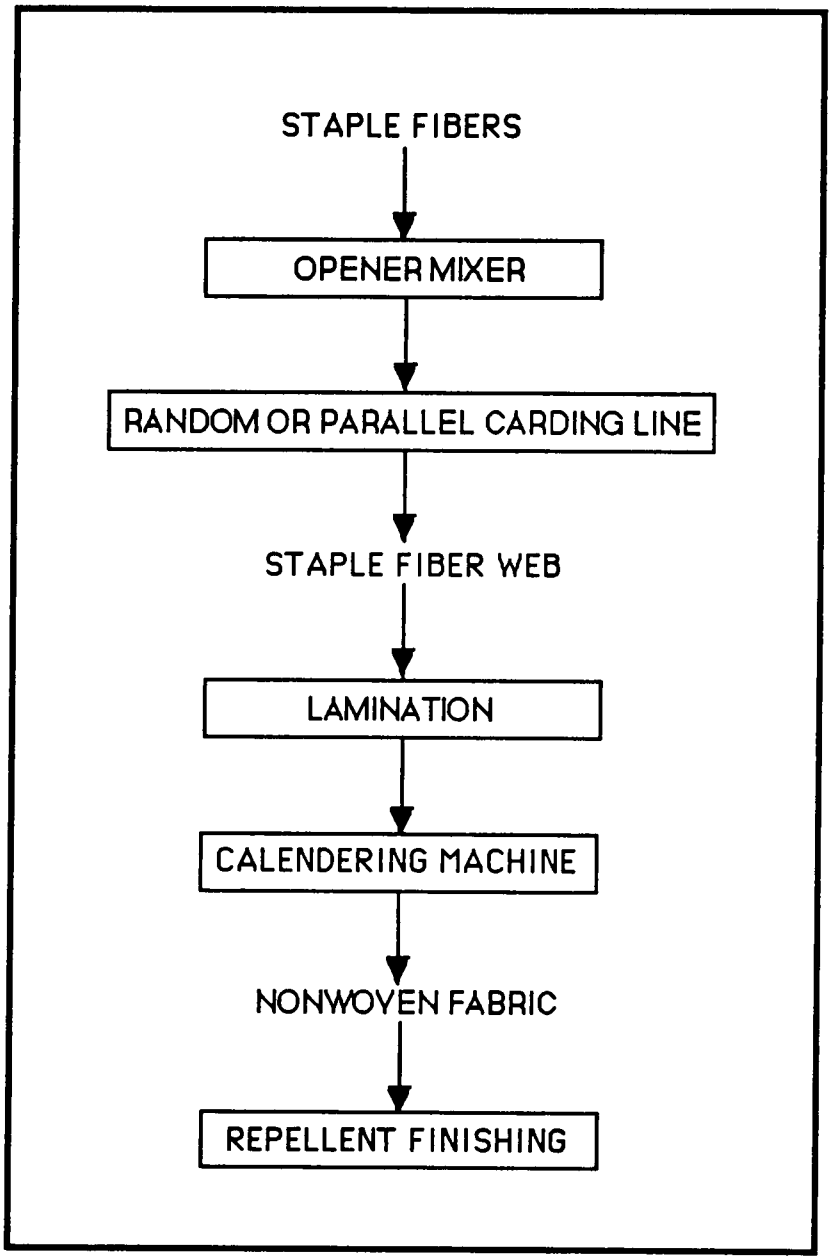


Fig. 1 -- Schematic diagram of the process used to make MSM laminates for Part A.

temperature is usually necessary because fabric and bond properties are affected by bonding temperature and nip roll pressure.

Thermal bonding process parameters. The surface speed of the calender rolls was maintained at 29 ft/min. The temperature range of the rolls were raised from a range of 114 - 133 °C (for top roll) and 117 - 126 °C (for bottom roll) to 128 - 135 °C (for top roll) and 127 - 132 °C (for bottom roll) based on the recommendations of the preliminary study [21]. The higher temperatures were utilized in order to achieve adequate bonding between the carded webs and the melt blown fabrics. The temperature of the calender rolls selected for the top roll ranged from 128 to 135 °C and the surface temperature selected for the bottom roll ranged from 127 to 132 °C depending on the fiber content and blend ratios. The pressure between the top and bottom rolls was increased as suggested by our previous study [21] to 250 pounds/linear inch (PLI) from 200 pounds/linear inch (PLI). This increased pressure was to facilitate adequate bonding.

From the process description, some important parameters that should be considered for the development of melt blown/staple fiber/melt blown (MSM) laminate nonwovens for medical uses are as follows:

Melt Blown Fabric

- Resin type
- Fabric weight

Staple Fiber Web

- Weight
- Constituent fibers
- Blend ratio with other staple fibers
- Fiber denier

- Fiber length

Thermal Bonding Process

- Pattern on engraved roll
- Percent area of raised pattern on engraved roll
- Nip pressure between rolls
- Temperatures of rolls
- Surface speed of calender rolls

The parameters, their levels, and the number of values selected are given in Table 1. The processing conditions for the MSM laminate samples are given in Table 2.

Repellent Finishing of MSM laminate fabrics. A fluorochemical finish was given to the MSM laminate samples in order to improve their repellency characteristics - toward water, oil, blood, alcohol, and other aqueous liquids - and barrier properties of the fabrics.

The padding technique, a conventional method of applying continuous finish was used to give the MSM laminate samples a fluorochemical finish. Padding is the most common method [19] of applying a fluorochemical finish. Padding is found to be suitable to treat nonwovens because it has the capability of giving an uniform and deep penetration of the treatment. In this technique, the sample is immersed in the chemical mixture and then passed through the nip of the rollers to squeeze out the excess chemicals from the saturated laminate by the application of nip pressure. The nip pressure is adjusted in order to get the desired wet pick up percentage (WPU%). Wet pick up is the amount of finish liquor absorbed by the laminate sample. The unfinished samples were weighed after being cut. The samples passed through the padding mangle for

Table 1. Parameters and their values for Part A.

PARAMETER	NUMBER OF LEVELS	VALUES
Melt Blown Fabric		
Resin	2	Himont VALTEC 442, Exxon PD 3495G
Fabric Weight	2	0.7 oz/yd^2, 0.5 oz/yd^2
Staple Fiber Web		
Constituent Fibers	2	Cotton (C), Polypropylene (PP)
Weight	1	1.0 oz/yd^2
Blend Level (C/PP)	4	100/0, 65/35, 50/50, 0/100
Fiber Denier:		
Cotton Denier	1	1.75 (Veratec 'Easy Street')
PP Denier	2	2.2 (Hercules T-185)
		3.0 (BASF Bico 'Merge 1080')
Fiber Length:		
Cotton Length	1	1.0 inch
PP Length	1	1.5 inch
Thermal Bonding Process		
Pattern of engraved roll	1	Diamond
Area percent of raised pattern	1	16.6%
Nip Pressure between Rolls	1	250 PLI
Temperature:		
Top Roll	4	128 °C, 133 °C, 134 °C, 135 °C
Bottom Roll	4	127 °C, 129 °C, 131 °C, 132 °C
Surface Speed of Rolls	1	29 ft./min

Table 2. Processing conditions of melt blown/staple fiber/melt blown laminate[1] fabrics.

Sample No.	Weight of Layers[2] (oz/yd^2)	Composition of Layers			Bonding Roll Temperature (°C)		Composition of Fabric	
	Top/Middle/Bottom	Top	Middle	Bottom	Top	Bottom	Cotton (%)	PP (%)
1	0.7/1.0/0.7	UT-1-24[3]	100% C	UT-1-24	128	129	41.8	58.2
2	0.7/1.0/0.7	UT-1-24	100% C	UT-1-24	134	129	41.8	58.2
3	0.7/1.0/0.5	UT-1-24	100% C	UT-1-17[4]	134	129	45.4	54.6
4	0.7/1.0/0.5	UT-1-24	65/35 C/PP[5]	UT-1-17	135	127	29.5	70.5
5	0.7/1.0/0.7	UT-1-24	65/35 C/PP[5]	UT-1-24	135	129	27.1	72.9
6	0.7/1.0/0.7	UT-1-24	100% PP[5]	UT-1-24	135	132	0	100
7	0.7/1.0/0.5	UT-1-24	100% PP[5]	UT-1-17	135	132	0	100
8	0.7/1.0/0.5	UT-1-24	100% BF PP[6]	UT-1-17	135	132	0	100
9	0.7/1.0/0.7	UT-1-24	100% BF PP[6]	UT-1-24	135	132	0	100
10	0.7/1.0/0.7	UT-1-24	50/50 C/PP	UT-1-24	135	131	20.8	79.2
11A	0.7/1.0/0	UT-1-24	50/50 C/PP	0	133	128	29.4	70.6
11B	0.7/1.0/0.7	UT-1-24	50/50 C/PP	UT-1-24	133	128	20.8	79.2
12A	0/1.0/0.5	0	50/50 C/PP	UT-1-17	133	128	33.3	66.7
12B	0.7/1.0/0.5	UT-1-24	50/50 C/PP	UT-1-17	133	128	22.7	77.3
13A	0/1.0/0.5	0	50/50 C/PP	UT-2-17[7]	135	128	33.3	66.7
13B	0.7/1.0/0.5	UT-2-24[8]	50/50 C/PP	UT-2-17	135	129	22.7	77.3

[1] 40-inch fabrics produced.
[2] Outer layers consisted of different weights of MB PP and the middle layer consisted of staple fiber.
[3] Himont Resin MB (0.7 oz/sq.yd).
[4] Himont Resin MB (0.5 oz/sq.yd).
[5] Hercules Grade T-185 PP.
[6] BASF bicomponent PP fiber.
[7] Exxon MB (0.5 oz/sq.yd).
[8] Exxon MB (0.7 oz/sq.yd).

fluorochemical finishing were weighed wet after finishing treatment. The wet pick up percentage was determined as follows:

$$WPU\% = \frac{\text{Weight of Padded Sample - Weight of Dry Sample}}{\text{Weight of Dry Sample}} \times 100$$

The wet pick up percentage of different laminate samples is given in Table 3.

Fluorochemical finishing was carried out at the UTK laboratory using a 18" wide padding mangle. The fluorochemical used to treat the fabrics was 5% "Zonyl" PPR Fabric Protector from The Du Pont Company. A wet pick up of 140% was planned for. The fabrics were given a fluorochemical finish in a padding mangle with two dips and two nips at a pressure of 30 psi. The finished fabrics were then cured in a convection oven at 250 ^{0}F for 3.5 minutes on a pin frame. The following fluorochemical formulation was used:

Padding Application (Planned wet pick up of 140%)

Ingredients	g/100
Zonyl PPR	3.6
Water	96.4
Total	100.0

Part B: Absorbency properties of laminates

Laminate Fabric Preparation

A schematic diagram for the preparation of the nonwoven laminate is given in Fig. 2. Fiber opening, carding, laminating with melt blown and/or spun bond fabrics, and calendering constitute the steps in the preparation of the laminate fabrics. Cotton/ramie was weighed, opened, and fed into a carding

Table 3. **Wet pick up percentage (WPU %) of MSM laminate fabrics.**

Sample #	WPU %
1	152.10
2	145.50
3	149.43
4	155.62
5	149.06
6	157.96
7	157.90
8	140.91
9	140.11
10	146.59
11A	136.79
11B	145.41
12A	143.22
12B	149.48
13A	143.64
13B	143.56

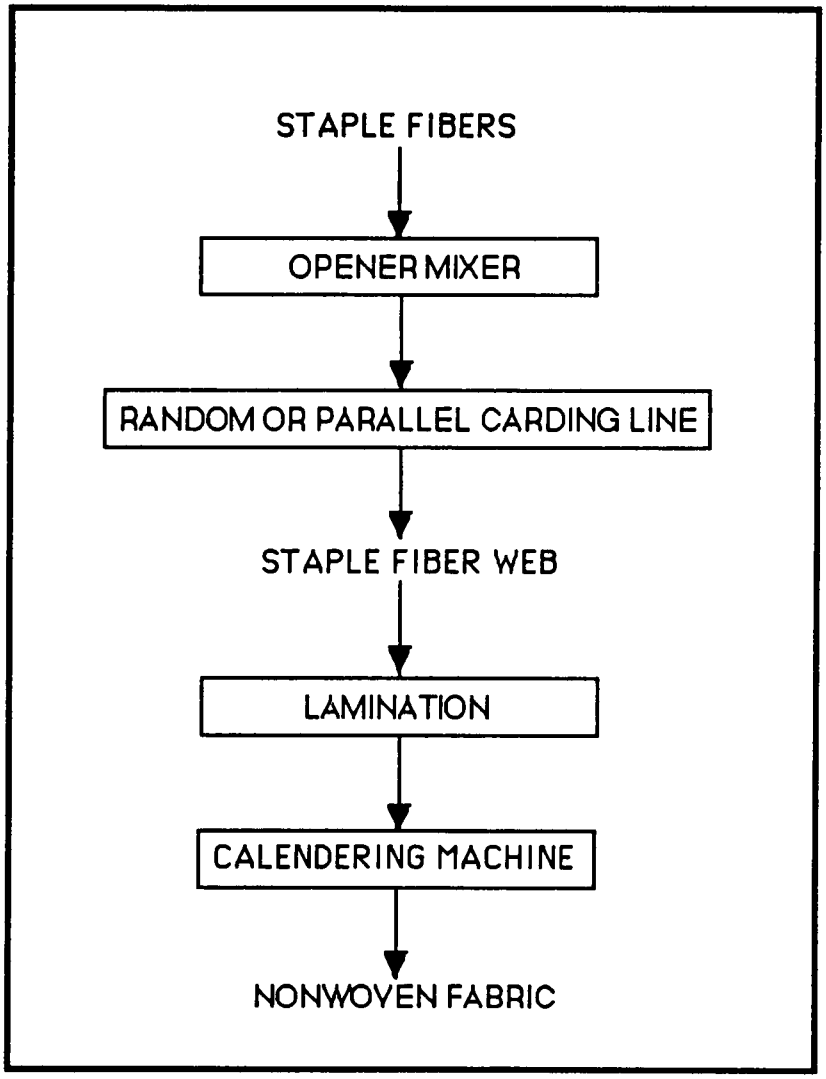


Fig. 2 -- Schematic diagram of the process used to make laminates for Part B.

machine. The carding machine used in this phase of the study was a Saco-Lowell card modified by Hollingsworth to a combination of flats and half granular clothing. The card prepared parallel-laid webs which are collected at the exit side of the card on a drum having a circumference of 150 cm and a width of 18 cm. The final weight of the web was the weight of the core desired in the laminate. The webs (of cotton or ramie) were then laminated with melt blown and/or spunbond fabrics ready for calendering. These samples were then thermal bonded by feeding them to the nip of the calender rolls. The webs (of cotton and ramie) were then laminated with melt blown/spun bond fabrics ready for the top patterned roll (320 mm diameter, having a bonding percentage of 14.66%) and bottom smooth roll (320 mm diameter) of the Kusters Calender. The temperature of the rolls and pressure applied at the nip of the rolls depended on the material constituting the top and bottom layers of the laminate. The surface speed of the calender rolls was kept constant at 9.1 m/min (10 yd/min) for all the fabrics. The parameters, their levels, and the number of values selected for Part B of the present study are given in Table 4. Sample specifications are given in Table 5.

Table 4. Parameters and their values for Part B.

PARAMETER	NUMBER OF LEVELS	VALUES
Melt Blown Fabric		
Polymer Composition of webs	7	EVA, EMA, Nylon 6, PET, PBT, PE, PP
Fabric Weight	5	0.25, 0.5, 0.7, 1.0, 1.5 oz/yd^2
Spunbond Fabric		
Polymer Composition of web	1	Polypropylene (PP)
Fabric Weight	1	0.6 oz/yd^2
Staple Fiber Web		
Constituent Fibers	2	Cotton (C), Ramie (R)
Weight	4	1.0, 2.0, 3.0, 4.0 oz/yd^2
Fiber Denier:		
Cotton Denier	1	1.75 (Veratec 'Easy Street')
Ramie Denier	1	Not determined
Fiber Length:		
Cotton Length	1	1.0 inch
Ramie Length	1	Not determined
Thermal Bonding Process		
Pattern of engraved roll	1	Diamond
Area percent of raised pattern	1	14.66%
Nip Pressure between Rolls	1	250 PLI
Temperature:		
Top Roll	5	44 °C, 88 °C, 105 °C, 125 °C, 134 °C
Bottom Roll	5	41 °C, 90 °C, 100 °C, 122 °C, 129 °C
Surface Speed of Rolls	1	29.9 ft./min

Table 5. Laminate Fabrics Bonded on Kusters Calender[1].

Sample No.	Sample Designation (Top Layer)	Polymer Composition of MB Webs (Top Layer)	Sample Designation (Bottom Layer)	Polymer Composition of Webs (Bottom Layer)	Weight of Core Web (oz/yd^2)
6	OC - 13 - 88 - 5	1.5 oz/yd^2 EVA	OC - 13 - 88 - 5	1.5 oz/yd^2 EVA	1.0 Cotton[2]
7	JA -12 - 88	1.0 oz/yd^2 EMA	JA -12 - 88	1.0 oz/yd^2 EMA	1.0 Cotton[2]
8	May 1 - 90 - 3	1.0 oz/yd^2 Nylon 6	May 1 - 90 - 3	1.0 oz/yd^2 Nylon 6	1.0 Cotton[2]
9A	OC - 25 - 90 - 2	1.0 oz/yd^2 Eastman PET 12270	OC - 25 - 90 - 2	1.0 oz/yd^2 Eastman PET 12270	1.0 Cotton[2]
9B	AU - 20 - 91 - 8	1.0 oz/yd^2 Celanese PBT 1300A	AU - 20 - 91 - 8	1.0 oz/yd^2 Celanese PBT 1300A	1.0 Cotton[2]
10	NO - 15 - 90 - 1B	1.0 oz/yd^2 PE	NO - 15 - 90 - 1B	1.0 oz/yd^2 PE	1.0 Cotton[2]
11	OC - 11 - 89 - 3	0.25 oz/yd^2 PP	OC - 11 - 89 - 3	0.25 oz/yd^2 PP	1.0 Cotton[2]
12	OC - 12 - 89 - 5	1.0 oz/yd^2 Blue PP	OC - 12 - 89 - 5	1.0 oz/yd^2 Blue PP	1.0 Cotton[2]
13	UT - 1 - 24	0.7 oz/yd^2 PP	UT - 1 - 24	0.7 oz/yd^2 PP	2.0 Cotton[2]
14	UT - 1 - 24	0.7 oz/yd^2 PP	UT - 1 - 24	0.7 oz/yd^2 PP	3.0 Cotton[2]
15	UT - 1 - 24	0.7 oz/yd^2 PP	UT - 1 - 24	0.7 oz/yd^2 PP	4.0 Cotton[2]
16	UT - 1 - 24	0.7 oz/yd^2 PP	UT - 1 - 24	0.7 oz/yd^2 PP	1.0 Cotton[2]

Table 5 (contd.). Laminate Fabrics Bonded on Kusters Calender.

Sample No.	Sample Designation (Top Layer)	Polymer Composition of MB Webs (Top Layer)	Sample Designation (Bottom Layer)	Polymer Composition of Webs (Bottom Layer)	Weight of Core Web (oz/yd^2)
17	UT - 1 - 24	0.7 oz/yd^2 PP	UT - 1 - 24	0.7 oz/yd^2 PP	1.0 Ramie
18	UT - 1 - 24	0.7 oz/yd^2 PP	100% PP SB	0.6 oz/yd^2 PP	3.0 Cotton[2]
19	UT - 1 - 24	0.7 oz/yd^2 PP	100% PP SB	0.6 oz/yd^2 PP	1.0 Ramie
20	UT - 1 - 24	0.7 oz/yd^2 PP	100% PP SB	0.6 oz/yd^2 PP	2.0 Ramie
21	UT - 1 - 24	0.7 oz/yd^2 PP	100% PP SB	0.6 oz/yd^2 PP	3.0 Ramie
22	UT - 1 - 24	0.7 oz/yd^2 PP	UT - 1 - 24	0.7 oz/yd^2 PP	-
23	UT - 1 - 24	0.7 oz/yd^2 PP	UT - 1 - 17	0.5 oz/yd^2 PP	-
24	OC - 11 - 89 - 3	0.25 oz/yd^2 PP	OC - 11 - 89 - 3	0.25 oz/yd^2 PP	-
25	UT - 1 - 24	0.7 oz/yd^2 PP	100% PP SB	0.6 oz/yd^2 PP	-

[1] Laminated and thermally bonded with a Kusters Calender with a diamond pattern with 14.7 % bonding area . Samples 6 and 7 were bonded at 150 PLI pressure with 41 °C on the top patterned roll and 41 °C on the bottom smooth roll at a fabric speed of 10yd/min (9.1 m/min) . Sample 10 was bonded using a top roll temperature of 88 °C and bottom roll temperature of 90 °C with 250 PLI and a fabric speed of 10yd/min (9.1 m/min). Sample11 was bonded using a top roll temperature of 105 °C and bottom roll temperature of 100 °C with 250 PLI and a fabric speed of 10yd/min (9.1 m/min). Samples 8, 9A, 9B, 12, 13, 14, 15, 16, and 17were bonded using a top roll temperature of 134 °C and bottom roll temperature of 129 °C with 250 PLI and a fabric speed of 10yd/min (9.1 m/min).The remainder of these samples, not otherwise designated, were laminated under the same conditions except the temperature of the top and bottom rolls were 125 °C and 122 °C respectively.

[2] Veratec "Easy Street" desized, scoured, and bleached cotton carded on 40 - inch Hollingsworth - On - Wheels card and with a combination of flats and half granular clothing. The webs were rolled up on a cylinder 18 cms wide and 1.5 meters in circumference.

CHAPTER 4

EXPERIMENTAL PROCEDURES

Testing Procedures and Standards

Part A: Barrier properties of MSM laminates

Properties that are generally required by medical nonwovens were evaluated using standard test procedures. A listing of the properties tested and the test procedures used is as follows:

Barrier. Barrier [22] refers to the ability of a fabric to resist strike-through of fluid and microorganisms. Barrier properties protect the operating room staff and the patient from infection.

Test Used	Test Procedure Used
Hydrostatic Pressure	AATCC Test Method 127-1989
Oil Repellency Rating	AATCC Test Method 118-1989
Water Impact Penetration	AATCC Test Method 42-1989
Water Spray Rating	AATCC Test Method 22-1989

Strength. Medical nonwovens [22] need to be strong enough to prevent tearing and puncturing all the way from manufacturing steps through use of the finished product.

Test Used	Test Procedure Used
Breaking Load	IST[1] 110.0 - 70 (82)
Elmendorf Tear Strength	IST 100.0 - 70 (R82)
Mullen Bursting Strength	IST 30.0 - 70 (R82)
Tensile Elongation	IST 110.0 - 70 (82)

Drapability and Comfort. Drapability [22] of a nonwoven fabric refers to its ability to conform to the shape of the object it is covering. The objects include patients, operating room tables and equipment.

Comfort [22] relates to breathability, selection of materials and product design.

Test Used	Test Procedure Used
Frazier Air Permeability	IST 70.1 - 70 (R82)
Cantilever Bending Length	ASTM D 1388-64

Part B: Absorbency properties of laminates

Laminate fabrics were bonded using the Kusters Calender and were tested for the following properties:

- Weight
- Thickness
- Mullen Bursting Strength
- Wicking Capacity
- Absorbent Capacity
- Retention Capacity

[1] INDA (Association of the Nonwovens Fabrics Industry) Standard Test.

Weight. A circular sample of 100 sq. cm area was used to determine the weight of the samples.

Thickness. The thickness of the samples was determined on the Ames Thickness Gauge (Model 85 - 0071) made by Testing Machines Inc.

Mullen Bursting Strength The bursting strength of the samples was determined on the Mullen Bursting Strength Tester in accordance to INDA Standard Test (IST) 30.0 - 70 (R82).

Wicking Capacity Test. The test is an adaptation of Harnett and Mehta's [23, 24] Transverse Wicking Plate Test. The schematic representation of the test equipment is shown in Fig. 3. A container holding the test liquid (in this case distilled water) is placed on a laboratory jack which rests on top of a balance. A funnel with a coarse (40 - 60 micron) glass frit is connected by a rubber hose to the container holding the test liquid. The test specimens(circular) are 100 sq. cm in area and cut randomly from a fabric that has been conditioned at 20 °C and 65% relative humidity overnight.

The water container is raised to a point at which the surface of the glass frit is moist, taking care to ensure that there is no water standing upon the frit. The test specimen is placed face side down on the frit and a 100 g circular weight is placed on top of the specimen. A stop-watch is started coinciding with the weight being placed on the specimen and the reading of water being lost from the container is recorded at 10 second intervals for a period of 3 minutes. The wicking capacity results are plotted on a 'time vs amount absorbed' curve.

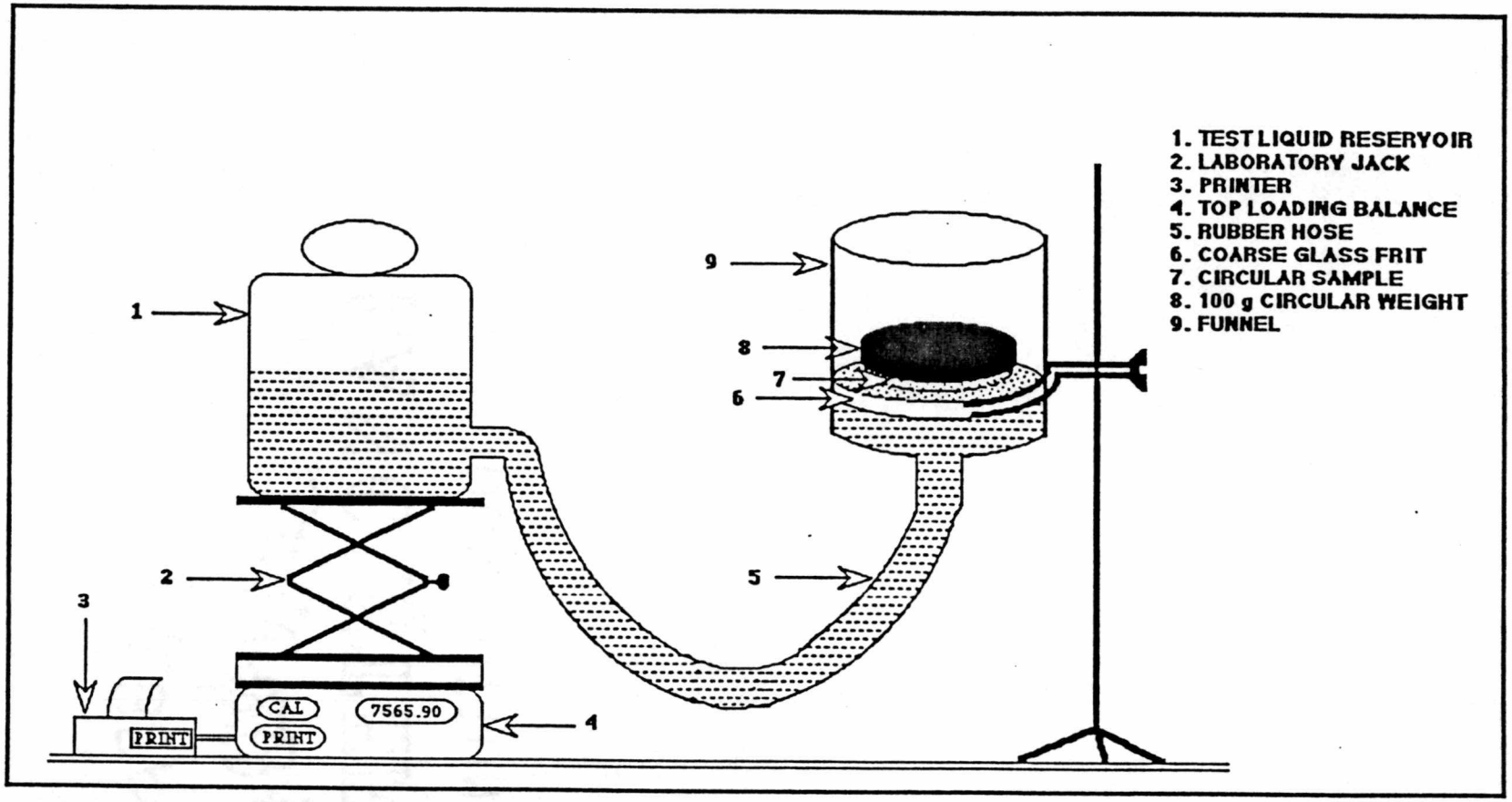


Fig. 3 -- Schematic diagram of wicking test equipment.

Absorbent Capacity. Two methods have been used to determine absorbent capacity.

Absorbent Capacity Test Method 1. Five specimens (6" x 6") were used for this test [24]. The samples were conditioned at 20 °C and 65% relative humidity. Theequipment needed for this test was a smooth surface with an attached clip that is tilted at 45° angle (metal clip board). The square samples were then weighed. After weighing, the samples were placed on the clipboard in such a way that only one corner of the sample was clamped under the clip on the board. Approximately 500 ml of distilled water was poured over the entire area of the sample resting at an angle of 45° on the clip board so as to thoroughly saturate the sample. The saturated specimen was allowed to drain for 3 minutes. The moistened sample was then carefully transferred to a balance and weighed. Absorbent capacity was determined in the following way:

$$\text{Absorbent capacity (g/g)} = \frac{\text{Weight of wet sample (g)- Weight of dry sample (g)}}{\text{Weight of dry sample (g)}}$$

The absorbent capacity was expressed in terms of grams of fluid absorbed per gram of fabric (g/g).

This test procedure was developed by Rebecca Layman and John Crouse [24] using the same equipment specified in INDA Standard Test 80.0 - 70 [R82] in order to determine absorbency in a simple test applicable to an industrial setting.

Absorbent Capacity Test Method 2. This is an adaptation of the test procedure developed at the Swedish Institute for Textile Research (TEFO) [24, 25]. The schematic representation of the test equipment is shown in Fig. 4. The test equipment consists of a funnel having a coarse (40-60 microns) glass frit. A separatory funnel is placed in such a way that it delivers 100 ml of test liquid (in

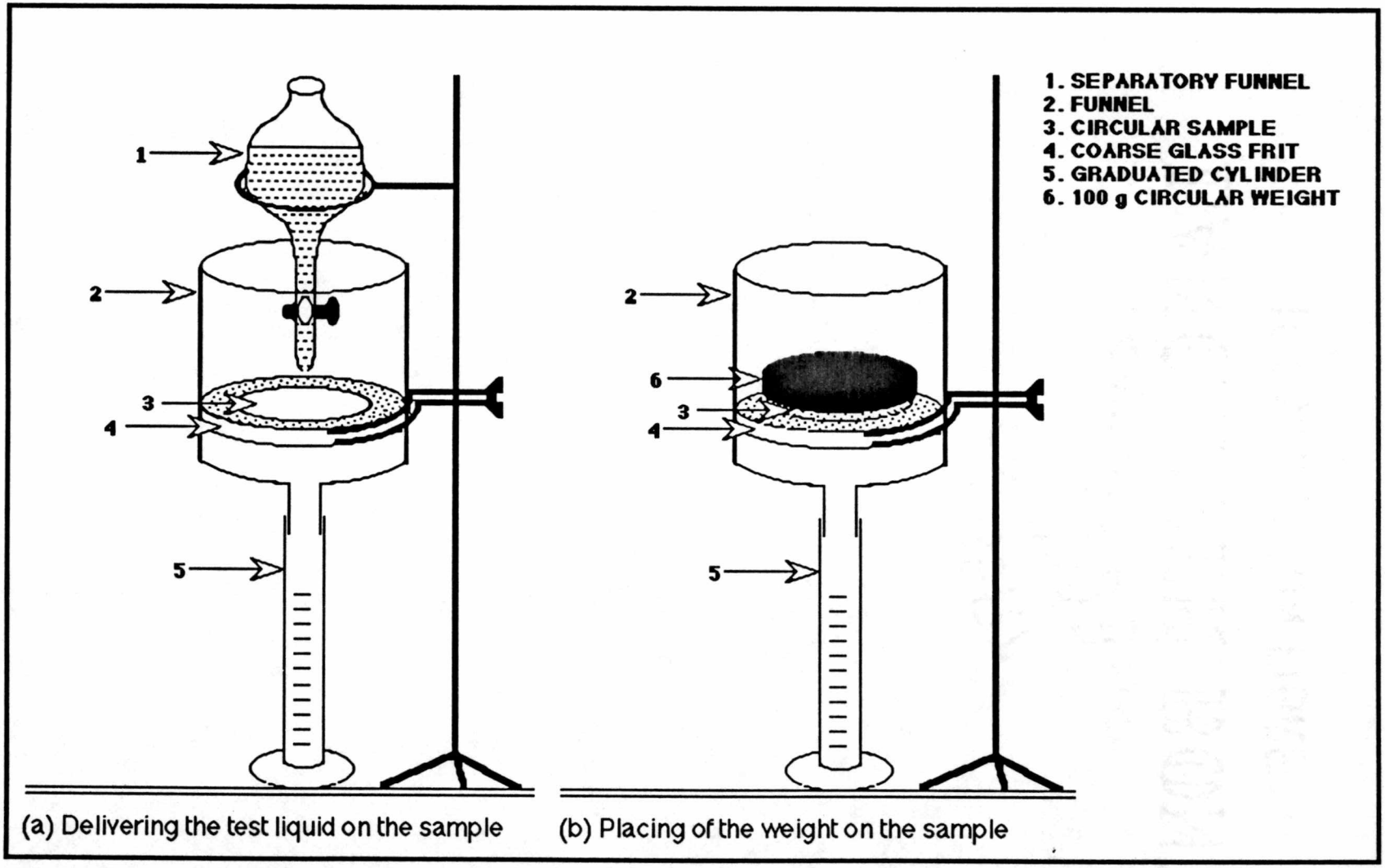


Fig. 4 -- Schematic diagram of absorbent capacity method 2 and retention capacity equipment.

this case distilled water) at a rate of 7 ml/sec from a height of 2.54 cm above the top side of the test specimen placed on the glass frit as shown in (a) of Fig. 4. This is done to saturate the test specimen. The test specimens(circular) must be 100 sq. cm in area and are conditioned at 20 °C and 65% relative humidity overnight. A 100 sq. cm circular weight of 100 g is then placed gently on the saturated specimen as shown in (b) of Fig. 4 and a stop-watch is started. In this test method, the weight is set in place after delivering the test liquid unlike the method of TEFO which has a weight (with a hole drilled in the center) placed on the specimen through which the test liquid is delivered. The saturated specimen is then allowed to drain for 10 minutes. The amount of liquid collected in a graduated collection cylinder (placed below the funnel) is utilized to determine the absorbent capacity (C) of the specimen in the following way:

$$C = a - b$$

Where, a = total liquid delivered (100 ml)

b = liquid unabsorbed (ml) under 100 Pa pressure

The results are reported to the nearest milliliter.

The only point in this test method [24]which is inconsistent with Shishoo's [25] proposed test is that the 100 gm circular weight (placed on the sample after delivering the liquid) did not have a built-in tube for liquid delivery at its center to the sample. In this test procedure the weight was placed on the sample after delivering the liquid.

vi. Retention Capacity. This test procedure is a continuation of Absorbent Capacity Method 2 [24, 25] mentioned earlier. The same equipment is used to determine retention capacity.

After evaluating absorbent capacity, the pressure applied on the specimen is increased to 3 kPa by placing a weight of 2.9 kg (in addition to 100 gm weight already there). The specimen is then allowed to drain for 5 minutes and the amount of liquid collected in a graduated collection cylinder is determined. An additional weight of 2 kg is added to increase the pressure applied to 5 kPa. The specimen is then allowed to drain for 5 more minutes and the amount of liquid collected in a graduated collection cylinder is determined. The retention capacity at 3 kPa and 5 kPa is determined by subtracting the test liquid unabsorbed at 3 kPa and 5 kPa from the absorption capacity (C). The retention capacity values are reported to the nearest milliliter.

Statistical Procedures

Part A: Barrier properties of MSM laminates

Wilcoxon Signed Rank Test. The Wilcoxon Signed Rank test was used to determine if the average differences in barrier, repellency, and physical properties were significantly different from zero when comparing MSM laminate fabrics before and after repellent finishing. The Wilcoxon Signed Rank test is a nonparametric analogue to the paired - difference t - test. This test assumes that each pair of observations is independent of other pairs. This test was performed using the SAS software [26, 27]. Since there are paired measurements (before and after repellent finishing) for each item (MSM laminate fabrics) in the sample, these are referred to as 'paired groups'. Since no assumptions are made regarding the specific distribution of the data in these groups, the nonparametric methods of statistical analysis were used to analyze the data. The Wilcoxon

Signed Rank test, being a nonparametric method determines if a significant difference exists between the paired groups.

CHAPTER 5

RESULTS AND DISCUSSION

Part A: Barrier properties of MSM laminates

The results obtained from the testing of the desired properties of the unfinished MSM laminates are shown in Tables 6, 7, and 8 and the results for the finished MSM laminates are shown in Tables 9, 10, and 11. The parameters whose effect on fabric properties was studied were the following (either singularly or a combination of two of them):

- Temperature of calender rolls.
- Weight of melt blown fabric.
- Resin used in melt blown fabric.
- Fluorochemical repellent finish used.

Temperature of Calender Rolls

Temperature of bottom roll and change in weight of melt blown fabric.

An increase in the bottom roll temperature combined with increased weight of the melt blown fabric appeared to contribute toward better bonding of the MSM laminate. The bottom roll contacts the entire surface of the fabric compared to the top patterned roll which bonds only a portion of the fabric. The temperature of the bottom roll should be lower than that of the top roll for this reason. With increased weight of melt blown fabric there appeared to be better bonding. Better bonding led to increased breaking strength of the laminate, as seen in Sample #5 in

Table 6. Barrier test results of unfinished melt blown/staple fiber/melt blown laminate fabrics.

Sample No.	Hydrostatic Pressure (cm)	Water Spray Rating (0 - 100)	Water Impact Penetration (g)	Oil Repellency Rating (0 - 8)
1	34	90	0.43	0
2	32	80	0.37	0
3	24	70	0.90	0
4	32	70	1.67	0
5	32	70	0.33	0
6	39	70	0.83	0
7	57	80	4.33	0
8	42	80	1.73	0
9	48	70	0.33	0
10	33	70	0.27	0
11A	22	90	1.03	0
11B	29	80	0.3	0
12A	20	80	>5 (22.33)	0
12B	27	80	4.37	0
13A	14	50	>5 (23.20)	0
13B	17	50	1.37	0

Table 7. **Bending length and air permeability test results of unfinished melt blown/staple fiber/melt blown laminate fabrics.**

Sample No.	Bending Length (cm)		Air Permeability	
			($ft^3/min/ft^2$)	($m^3/min/m^2$)
	MD	CD		
1	7.22	5.63	32.00	0.16
2	7.91	5.97	30.51	0.16
3	7.02	5.27	32.84	0.17
4	7.24	5.31	35.30	0.18
5	7.71	5.60	30.00	0.15
6	7.40	5.14	30.90	0.16
7	6.98	5.20	36.70	0.19
8	7.37	5.14	36.42	0.19
9	7.53	5.49	30.17	0.15
10	7.91	5.22	29.70	0.15
11A	3.86	2.63	65.50	0.33
11B	8.35	5.63	30.64	0.16
12A	3.49	2.19	96.65	0.49
12B	7.83	5.43	35.23	0.18
13A	3.63	2.33	100.63	0.51
13B	6.92	5.36	43.25	0.22

Table 8. Strength test results of unfinished melt blown/staple fiber/melt blown laminate fabrics.

Sample No.	Bursting Strength		Breaking Strength		Elongation		Tear Strength	
	(psi)	(kPa)	(Kg/cm)		(%)		(g)	
			MD	CD	MD	CD	MD	CD
1	11	75.79	0.83	0.54	14.0	21.2	98	174
2	9.4	64.77	0.90	0.49	11.6	20.0	84	126
3	7.7	53.05	0.80	0.43	10.4	22.8	68	114
4	13.5	93.02	0.90	0.44	17.2	21.6	126	314
5	14.3	98.53	0.97	0.49	15.2	22.8	136	400
6	19.1	131.60	0.97	0.50	20.0	24.8	158	694
7	17.3	119.20	0.88	0.40	22.4	21.6	126	488
8	19.4	133.67	1.46	0.45	24.8	24.4	166	248
9	19.1	131.60	1.39	0.54	26.0	24.0	112	292
10	14	96.46	1.03	0.46	15.2	19.6	94	412
11A	10.7	73.72	0.58	0.20	16.4	20.0	64	226
11B	11.4	78.55	0.93	0.43	16.4	20.8	86	460
12A	10.1	69.59	0.42	0.13	15.6	16.4	58	142
12B	14.4	99.22	0.87	0.39	14.4	20.4	90	404
13A	11.2	77.17	0.47	0.14	18.0	16.0	66	116
13B	13.5	93.02	0.87	0.44	19.6	18.4	88	344

Table 9. Barrier test results of finished melt blown/staple fiber/melt blown laminate fabrics.

Sample No.	Hydrostatic Pressure (cm)	Water Spray Rating (0 - 100)	Water Impact Penetration (g)	Oil Repellency Rating (0 - 8)
1	45	90	0.23	8
2	44	90	0.27	8
3	40	80	0.33	8
4	38	80	0.13	7
5	42	90	0.23	8
6	39	80	0.13	7
7	32	90	0.27	8
8	35	80	0.17	6
9	40	70	0.13	6
10	41	80	0.13	8
11A	32	90	0.93	8
11B	39	80	0.17	7
12A	25	80	>5 (6.86)	7
12B	36	80	0.13	8
13A	18	70	>5 (10.53)	7
13B	33	70	0.23	8

Table 10. **Bending length and air permeability test results of finished melt blown/staple fiber/melt blown laminate fabrics.**

Sample No.	Bending Length (cm)		Air Permeability	
			($ft^3/min/ft^2$)	($m^3/min/m^2$)
	MD	CD		
1	6.92	5.60	28.28	0.14
2	6.67	5.34	27.93	0.14
3	6.87	5.65	32.24	0.16
4	6.88	5.10	35.20	0.18
5	6.96	5.80	27.76	0.14
6	6.48	5.06	29.91	0.15
7	6.98	5.67	29.14	0.15
8	6.58	5.41	29.65	0.15
9	6.45	5.24	28.19	0.14
10	7.58	5.39	27.33	0.14
11A	3.42	2.33	62.32	0.13
11B	7.42	5.01	24.82	0.17
12A	2.07	2.03	96.05	0.20
12B	7.10	4.86	32.96	0.32
13A	2.01	1.97	94.85	0.49
13B	5.29	5.36	40.12	0.48

Table 11. Strength test results of finished melt blown/staple fiber/melt blown laminate fabrics.

Sample No.	Bursting Strength		Breaking Strength		Elongation		Tear Strength	
	(psi)	(kPa)	(kg/cm)		(%)		(g)	
			MD	CD	MD	CD	MD	CD
1	10.80	74.41	0.80	0.48	16	22	76	108
2	10.65	73.38	0.76	0.46	14	14	66	104
3	10.45	72.00	0.69	0.39	14	26	62	100
4	14.14	97.42	0.81	0.39	20	16	92	312
5	13.95	96.12	0.86	0.48	20	32	92	326
6	17.05	117.47	0.91	0.46	38	22	146	664
7	16.20	111.62	0.86	0.41	16	20	122	388
8	18.70	128.84	1.35	0.46	30	26	136	354
9	18.85	129.88	1.41	0.51	30	32	114	404
10	13.25	91.29	0.86	0.42	14	26	82	408
11A	10.75	74.07	0.51	0.20	18	18	60	192
11B	12.15	83.71	0.82	0.45	18	18	84	428
12A	9.65	66.49	0.14	0.13	16	18	58	104
12B	12.75	87.85	0.76	0.40	16	26	80	360
13A	10.45	72.00	0.15	0.15	12	12	60	108
13B	13.45	92.67	0.81	0.39	20	18	88	340

comparison to Sample #4, in which every other parameter was the same as Sample #4 except for the increased bottom roll temperature of 2 °C and increased weight of the melt blown fabric used for the bottom side of the laminate. Increased bonding and increased breaking strength would be expected to reduce the elongation-to-break, as seems to be the case. Improved bonding should also result in increased fabric stiffness as appears to be supported by an increase in bending length for Sample #5. An increase in the bursting strength of #5 can be attributed to the fact that #5 is a laminate structure having melt blown fabrics of 0.7 oz/yd^2 weight on both sides of the staple fiber web. Sample #5, having higher weight of melt blown fabric, had lower air permeability than #4 as expected because air permeability decreases with an increase in the basis weight of melt blown fabric.

Temperature of rolls and resin used in melt blown fabrics. Samples #12B and 13B differed in just two parameters. Sample #13B had both an increased top and bottom roll temperature and outer layers of melt blown fabrics (of same weight as Sample #12B) made of Exxon Chemical resin. These differences in the two samples did not lead to differences in breaking strength, but did result in a notable difference in elongation. This difference in elongation may be attributed to the fact that Exxon melt blown materials inherently have more elongation capability (MD and CD Elongation of UT-2-24 are 45.6% and 52.0% respectively and MD and CD Elongation of UT-2-17 are 38% and 48.8% respectively) than Himont melt blown(MD and CD Elongation of UT-1-24 are 33.2% and 49.2% respectively and MD and CD Elongation of UT-1-17 are 36.4% and 44% respectively). Sample #13B appeared to have lower bending

length which may be due to reduced stiffness. Sample #13B also had lower bursting strength than Sample #12B.

Weight of melt blown fabrics

A reduction in the weight of the melt blown fabric (as seen in Sample #7 in comparison to Sample #6, which had every other parameter equal to those of Sample #6 except for decreased weight - 0.5 oz/yd^2 instead of 0.7 oz/yd^2 - of the melt blown fabric) appeared to lead to a decrease in breaking strength of Sample #7. This is logical because the laminate was of lesser weight and could carry less load. Possible reduction in bonding because of the lower weight (0.5 oz/yd^2) of the melt blown web may also be a reason for the decrease in breaking strength of Sample #6. Before normalization of the weights of the laminate samples # 6 and 7 a 10% difference in breaking strength was found. Upon normalization, the breaking strength of the two samples was found to be not very different. This is an indication that higher basis weight MB layers contributed to greater strength of the laminate. The laminate transfers the load to the core of the material (here the web); hence, the laminate will elongate more before it breaks. This would be expected to contribute to an increase in elongation. Lower weight of the laminate would also be expected to result in less fabric stiffness, thereby reducing its bending length as well as to increase the air permeability as found with Sample #7.

Different behavior was observed in the case of samples #8 and 9 which had a core web of BASF Bicomponent PP fiber Merge 1080. Since sample #8 had a lower weight fabric (0.5 oz/yd^2) at the bottom, the heat transfer to the bicomponent fiber was enhanced. This caused the surface layer of the

bicomponent fiber web to melt, which appeared to lead to better bonding. Better bonding should lead to increased breaking strength. Better bonding and increased breaking strength would be expected to reduce the elongation-to-break. By virtue of being a lower weight fabric it was expected to have decreased stiffness, as demonstrated in a reduction in bending length. This has also resulted in Sample #8 having increased air permeability.

Samples # 11A, 12A, and 13A have melt blown fabrics only on one side of the staple fiber web (unlike all other laminates having melt blown fabrics on both sides). This appears to account for the fact that these samples had a lower breaking strength than did the other laminates. They are expected to be less stiff, which was supported by the fact that these samples had lower bending length values. These samples still have notable bursting strength. Among this group, #11A had the greatest breaking strength because it makes use of 0.7 oz/yd^2 melt blown fabric. The elongation of #11A is lower in comparison to #13A which used Exxon Chemical melt blown fabric having greater elongation than the Himont melt blown fabric. Having melt blown fabric only on one side appeared to have contributed toward these samples having greater air permeability than other samples in the study. Samples #12A and #13A, having melt blown fabrics weights of 0.5 oz/yd^2, had substantially greater air permeability than Sample #11A.

Samples #11B and #12B were similar in all parameters except that #12B had a different melt blown fabric of weight 0.5 oz/yd^2 on the bottom. The observation that Sample #11B appeared to have higher breaking strength than Sample #12B may be attributed to a symmetric sandwich structure (having same melt blown fabric of 0.7 oz/yd^2 on both sides of the web). Having lower weight,

Sample #12B is expected to have lower stiffness, as was supported by it having a lower bending length.

Fluorochemical Repellent Finish

The unfinished MSM laminate samples displayed the higher water spray ratings. This can be attributed to the fact that the melt blown fabrics were made of polypropylene fibers which are hydrophobic by nature.

The water impact penetration test showed that the use of melt blown fabrics had in fact resulted in lower water impact values indicating higher resistance to the penetration of water. The only exceptions were the two-layer laminate samples (Samples #12A and #13A), which showed water impact values higher than 5 gms. It was observed that the resistance to water impact penetration increased as air permeability of the laminate samples decreased, . This is because the penetration through the laminate samples decreases with a decrease in permeability. All the MSM laminate samples displayed a very poor rating of 0.0 for oil repellency.

The fluorochemically finished samples were tested for barrier, strength, drapability and comfort properties using the same test procedures as given earlier. The results for the finished samples are compared to those of the unfinished MSM laminate fabrics.

Barrier Properties. The hydrostatic pressure levels were already notably high with the unfinished samples, attesting to the good barrier properties provided by the melt blown webs. However, the repellent finished samples 1, 2, and 3 which contained only cotton staple fiber in the middle layer had much higher hydrostatic

pressure levels than the corresponding unfinished samples. These three samples also had generally greater hydrostatic pressure values than the finished samples with only PP in the middle layer. On the other hand, the hydrostatic pressures of most of the samples with only PP in the core were notably decreased by repellent finishing. The water spray rating of the majority of the finished samples was seen to have increased as a result of fluorochemical finishing. The greatest advantage in applying a fluorochemical finish was seen in the increase of oil repellency rating from a very poor 0.0 (in unfinished samples) to an excellent range of 6.0 - 8.0 in fluorochemically finished samples. Again, the fluorochemically finished samples containing only cotton in the core consistently had the highest oil repellency values of 8.0.

It can be mentioned that the very objective of giving a fluorochemical finish (i.e. to improve repellency characteristics and barrier properties of the MSM laminates) has been achieved. These improved barrier properties make the MSM laminates very suitable for operating room usage, since barrier properties are the most critical properties necessary in operating room clothing.

Strength Properties. Properties important under this category were breaking strength, tensile elongation, bursting strength, and tear strength. These properties are important for the laminate to be used in the operating room. It has been observed [28] that operating room personnel now have the experience and expertise necessary for using the fabrics in a way that minimizes damage during usage.

Bursting strength values have not changed significantly between unfinished and finished laminate samples. Breaking strength values were significantly higher in unfinished laminates. Higher elongation-at-break in the

finished laminate samples may be because of the heat application during curing which imparts some stretch to the fibers.

Drapability and Comfort Properties. Properties considered under this category are bending length and air permeability. These properties are critical for the performance of the product in the operating room.

Among the finished MSM laminate samples it was seen that the bending length values did change significantly. It was noted that the bending length of the finished MSM laminate samples was lower than that for the unfinished MSM laminate samples. This decrease in bending length indicates a reduction in stiffness of the finished samples. This reduction in stiffness was expected because the fabric had gone through the padding and curing process which improved the softness of the resultant laminate. This improved drapability is another advantage of the finishing process.

In regards to air permeability, there was a reduction in the air permeability of the finished laminates. This reduction may be attributed to the padding process which uses a nip pressure which could lead to denser, less open laminates.

Statistical Analysis of data

One of the objectives of Part A of the present study was to apply a fluorochemical treatment to the laminates in order to improve repellency characteristics - to water, oil, blood, alcohol, and other aqueous liquids - and barrier properties of the laminate fabrics. In order to determine if the results obtained from finished fabrics were statistically significant from unfinished fabrics

the Wilcoxon Signed Rank test was used. This test determined if the average difference in physical properties of MSM laminate fabrics before and after repellent finishing was significantly different from zero. The variable was the average difference in properties between unfinished and repellent finished laminates. The Wilcoxon Signed Rank test was performed using the SAS software. The results obtained from the Wilcoxon Signed Rank test are given in Figure 5.

While comparing paired groups (as is being done here) by using the Wilcoxon Signed Rank test, the null hypothesis (H_o) is that the mean difference between the groups is zero, and the alternative hypothesis (H_a) is that the mean difference between the groups is different from zero. In the Wilcoxon Signed Rank test, the hypotheses are tested by calculating a test statistic from the data and comparing its value to that expected if the null hypothesis were to be true. For the Wilcoxon Signed Rank test, the two possible outcomes are: i) the probability (p) value is lower than the reference probability (0.05 in this study), or ii) the probability (p) value is higher than the reference probability. If the former outcome is obtained, the result is statistically significant, the null hypothesis is rejected, and it is concluded that the mean difference between the paired groups is significantly different from zero. If the latter outcome is obtained, the null hypothesis is not rejected, and it is concluded that there is not sufficient evidence to say that the mean difference between the paired groups is significantly different from zero.

For Part A of the study, the hypotheses are:

H_o : The mean difference in the properties of the unfinished and finished MSM laminate fabrics is not significantly different from zero.

H_a : The mean difference in the properties of the unfinished and finished MSM laminate fabrics is significantly different from zero.

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	0.793125		Sum	12.69
Std Dev	0.510708		Variance	0.260823
Skewness	0.23193		Kurtosis	- 0.95194
USS	13.9771		CSS	3.912344
CV	64.3919		Std Mean	0.127677
T:Mean=0	6.211962		Prob > |T|	0.0001
Num ¬ = 0	15		Num > 0	15
M (Sign)	7.5		Prob > |M|	0.0001
Sgn Rank	60		Prob > |S|	0.0001

Comparison of MD Bending Length

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	0.1075		Sum	1.72
Std Dev	0.345205		Variance	0.119167
Skewness	- 0.02017		Kurtosis	- 0.91427
USS	1.9724		CSS	1.7875
CV	321.1212		Std Mean	0.086301
T:Mean=0	1.245636		Prob > |T|	0.2320
Num ¬ = 0	15		Num > 0	10
M (Sign)	2.5		Prob > |M|	0.3018
Sgn Rank	20		Prob > |S|	0.2769

Comparison of CD Bending Length

Figure 5. Wilcoxon Signed Rank Test results.

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	0.17875		Sum	2.86
Std Dev	1.147995		Variance	1.317892
Skewness	- 0.92377		Kurtosis	1.849765
USS	20.2796		CSS	19.76837
CV	642.2348		Std Mean	0.286999
T:Mean=0	0.622825		Prob > |T|	0.5428
Num ¬ = 0	16		Num > 0	11
M (Sign)	3		Prob > |M|	0.2101
Sgn Rank	**20.5**		**Prob > |S|**	**0.3035**

Comparison of Bursting Strength

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	3.105625		Sum	49.69
Std Dev	2.276998		Variance	5.18472
Skewness	0.681904		Kurtosis	- 0.5099
USS	232.0893		CSS	77.77079
CV	73.31851		Std Mean	0.569249
T:Mean=0	5.455648		Prob > |T|	0.0001
Num ¬ = 0	16		Num > 0	16
M (Sign)	8		Prob > |M|	0.0001
Sgn Rank	**68**		**Prob > |S|**	**0.0001**

Comparison of Air Permeability

Figure 5 (contd.). Wilcoxon Signed Rank Test results.

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	12.625		Sum	202
Std Dev	13.53945		Variance	183.3167
Skewness	1.124752		Kurtosis	0.447166
USS	5300		CSS	2749.75
CV	107.2432		Std Mean	3.384862
T:Mean=0	3.729842		Prob > |T|	0.0020
Num ¬ = 0	14		Num > 0	13
M (Sign)	6		Prob > |M|	0.0018
Sgn Rank	**51**		**Prob > |S|**	**0.0004**

Comparison of MD Tear Strength

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	15.875		Sum	254
Std Dev	55.86874		Variance	3121.317
Skewness	- 1.28621		Kurtosis	1.987307
USS	50852		CSS	46819.75
CV	351.9291		Std Mean	13.96719
T:Mean=0	1.136593		Prob > |T|	0.2735
Num ¬ = 0	16		Num > 0	14
M (Sign)	6		Prob > |M|	0.0042
Sgn Rank	**37**		**Prob > |S|**	**0.0559**

Comparison of CD Tear Strength

Figure 5 (contd.). Wilcoxon Signed Rank Test results.

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	0.110625		Sum	1.77
Std Dev	0.087899		Variance	0.007726
Skewness	1.171212		Kurtosis	1.590133
USS	0.3117		CSS	0.115894
CV	79.4568		Std Mean	0.021975
T:Mean=0	5.034182		Prob > |T|	0.0001
Num ¬ = 0	16		Num > 0	15
M (Sign)	7		Prob > |M|	0.0005
Sgn Rank	**66**		**Prob > |S|**	**0.0001**

Comparison of MD Breaking Strength

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	0.018125		Sum	0.29
Std Dev	0.026887		Variance	0.000723
Skewness	0.063116		Kurtosis	- 1.66852
USS	0.0161		CSS	0.010844
CV	148.3427		Std Mean	0.006722
T:Mean=0	2.696459		Prob > |T|	0.0166
Num ¬ = 0	14		Num > 0	9
M (Sign)	2		Prob > |M|	0.4240
Sgn Rank	**34.5**		**Prob > |S|**	**0.0251**

Comparison of CD Breaking Strength

Figure 5 (contd.). Wilcoxon Signed Rank Test results.

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	- 2.175		Sum	- 34.8
Std Dev	5.362524		Variance	28.75667
Skewness	- 1.37896		Kurtosis	5.072693
USS	507.04		CSS	431.35
CV	- 246.553		Std Mean	1.340631
T:Mean=0	- 1.62237		Prob > |T|	0.1255
Num ¬ = 0	16		Num > 0	3
M (Sign)	- 5		Prob > |M|	0.0213
Sgn Rank	**- 36**		**Prob > |S|**	**0.0634**

Comparison of MD Elongation

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	- 0.7		Sum	- 11.2
Std Dev	4.724969		Variance	22.32533
Skewness	- 0.39689		Kurtosis	- 0.87154
USS	342.72		CSS	334.88
CV	- 675.996		Std Mean	1.181242
T:Mean=0	- 0.5926		Prob > |T|	0.5623
Num ¬ = 0	16		Num > 0	8
M (Sign)	0		Prob > |M|	1.0000
Sgn Rank	**- 9**		**Prob > |S|**	**0.6591**

Comparison of CD Elongation

Figure 5 (contd.). Wilcoxon Signed Rank Test results.

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	- 4.8125		Sum	- 77
Std Dev	10.5402		Variance	111.0958
Skewness	1.719403		Kurtosis	3.35424
USS	2037		CSS	1666.437
CV	- 219.017		Std Mean	2.63505
T:Mean=0	- 1.82634		Prob > |T|	0.0878
Num ¬ = 0	15		Num > 0	3
M (Sign)	- 4.5		Prob > |M|	0.0352
Sgn Rank	**- 35.5**		**Prob > |S|**	**0.0427**

Comparison of Hydrostatic Pressure

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	- 7.5		Sum	- 120
Std Dev	7.745967		Variance	60
Skewness	- 0.49181		Kurtosis	- 1.06227
USS	1800		CSS	900
CV	- 103.28		Std Mean	1.936492
T:Mean=0	- 3.87298		Prob > |T|	0.0015
Num ¬ = 0	9		Num > 0	0
M (Sign)	- 4.5		Prob > |M|	0.0039
Sgn Rank	**- 22.5**		**Prob > |S|**	**0.0039**

Comparison of Water Spray Rating

Figure 5 (contd.). Wilcoxon Signed Rank Test results.

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	2.6825		Sum	42.92
Std Dev	4.663649		Variance	21.74962
Skewness	2.219278		Kurtosis	4.091868
USS	441.3772		CSS	326.2443
CV	173.8546		Std Mean	1.165912
T:Mean=0	2.300774		Prob > |T|	0.0362
Num ¬ = 0	16		Num > 0	16
M (Sign)	8		Prob > |M|	0.0001
Sgn Rank	68		Prob > |S|	0.0001

Comparison of Water Impact Penetration

Univariate Procedure Moments				
N	16		Sum Wgts	16
Mean	- 7.4375		Sum	- 119
Std Dev	0.727438		Variance	0.529167
Skewness	0.941715		Kurtosis	- 0.28436
USS	893		CSS	7.9375
CV	- 9.78068		Std Mean	0.18186
T:Mean=0	- 40.8969		Prob > |T|	0.0001
Num ¬ = 0	16		Num > 0	0
M (Sign)	- 8		Prob > |M|	0.0001
Sgn Rank	- 68		Prob > |S|	0.0001

Comparison of Oil Repellency Rating

Figure 5 (contd.). Wilcoxon Signed Rank Test results.

In the Wilcoxon Signed Rank test results (Figure 5), one needs to look at the last row labeled as *Sgn Rank*. This row gives the value of the *signed rank statistic* and also its *associated probability*. In the case of "MD Bending Length", the signed rank statistic was 60 and its associated probability (p-value) was 0.0001. Since the p-value was less than 0.05 (associated with a reference 5% significance level), the result is statistically significant, the null hypothesis could be rejected, and it could be concluded that there was a significant difference between the MD Bending Length of unfinished and finished MSM laminate fabrics. The finished fabrics were found to have lower bending length which is an indication that they were less stiff than unfinished fabrics. In the case of "CD Bending Length", the signed rank statistic was 20 and its associated probability (p-value) was 0.2769. Since the p-value is higher than 0.05, the result was not statistically significant, the null hypothesis cannot be rejected, and it was concluded that there was no significant difference between the CD Bending Length of unfinished and finished MSM laminate fabrics.

From Figure 5, it was seen that the unfinished MSM laminate fabrics had higher air permeability, higher MD tear strength, and higher MD and CD breaking strength than finished MSM laminate fabrics. The repellent finished fabrics displayed lower MD bending length, higher hydrostatic pressure, higher water spray rating, lower water impact penetration, and higher oil repellency rating than unfinished MSM laminate fabrics.

The Wilcoxon Signed Rank test showed that the repellency and barrier properties of MSM laminate fabrics have shown a significant improvement with the application of a repellent fluorochemical finish.

Comparison of MSM laminates to SMS

The test results of SMS fabrics of Kimberly-Clark are given in Table 12, 13, and 14 for the purpose of comparing the MSM laminates of the present study with SMS fabrics. Two weights (1.8 oz/yd^2 and 2.3 oz/yd^2) and unfinished and repellent finished types were tested.

The unfinished SMS fabrics displayed better barrier, strength, and drapability and comfort properties than unfinished MSM laminate fabrics. The hydrophobic nature of polypropylene material used in all the three layers accounted for the unfinished SMS fabrics displaying better water repellency properties than the unfinished MSM laminate fabrics. Both displayed similar oil repellency properties. SB fabrics used as the outer layers contributed to the SMS fabrics displaying higher strength properties than MSM laminate fabrics, both in the unfinished and finished conditions. The SB filaments undergo considerable drawing and orientation after quenching and this leads to higher strength of SB fabrics. The MSM laminate fabrics displayed greater air permeability than SMS fabrics in the unfinished and finished conditions. This can be accounted for by the presence of MB layers and cotton core webs.

The comparison between finished SMS fabrics and MSM laminate fabrics showed that the barrier properties of the MSM laminate fabrics is comparable to or exceeds that of the SMS fabrics in some cases. The presence of cellulosic material in the core of the MSM laminate fabrics could be the reason for slightly higher water impact penetration values.

Table 12 . Barrier test results of unfinished and finished SMS fabrics.

Sample ID	Hydrostatic Pressure (cm)	Water Spray Rating (0 - 100)	Water Impact Penetration (g)	Oil Repellency Rating (0 - 8)
1.8 oz/sq.yd UF	50	90	0	0
1.8 oz/sq.yd F	62	70	0	8
2.3 oz/sq.yd UF	77	90	0	0
2.3 oz/sq.yd F	58	70	0	7.5

UF = Unfinished SMS fabric.
F = Finished SMS fabric.

Table 13. Bending length and air permeability test results of unfinished and finished SMS fabrics.

Sample ID	Bending Length (cm)		Air Permeability ($ft^3/min/ft^2$)	Air Permeability ($m^3/min/m^2$)
	MD	CD		
1.8 oz/sq.yd UF	3.68	4.04	26.37	0.132
1.8 oz/sq.yd F	3.93	2.70	16.77	0.083
2.3 oz/sq.yd UF	4.62	4.88	13.66	0.068
2.3 oz/sq.yd F	3.90	2.94	11.9	0.059

UF = Unfinished SMS fabric.
F = Finished SMS fabric.

Table 14. Strength test results of unfinished and finished SMS fabrics.

Sample ID	Bursting Strength (psi)	Bursting Strength (kPa)	Breaking Strength (kg/cm)		Elongation (%)		Tear Strength (g)	
			MD	CD	MD	CD	MD	CD
1.8 oz/sq.yd UF	39.5	272.16	1.42	1.59	35.6	34.4	853	1209
1.8 oz/sq.yd F	39.3	270.78	1.49	1.35	22.0	28.4	613	660
2.3 oz/sq.yd UF	40.3	277.67	1.32	1.66	31.2	35.2	1179	1755
2.3 oz/sq.yd F	42.5	292.83	1.59	1.33	24.8	27.6	641	746

UF = Unfinished SMS fabric.
F = Finished SMS fabric.

Part B: Absorbency properties of laminates

The results obtained from the different tests are given in Tables 15, 16, 17, and 18 and in Figures 6 through 32[2] . The variables which were studied are as follows (either singularly or a combination of them):

- Weight of melt blown (MB) layer.
- Spunbond (SB) layer.
- Weight of cotton core.
- Weight of ramie core.

Bursting Strength

From Table 15, it can be seen that the bursting strength of the laminate fabrics increased with an increase in i) weight of MB layers, ii) weight of the cotton core, and iii) weight of the ramie core.

With an increase in the weight of the MB layer an increase in the bursting strength was seen. Sample #12 which had outer MB layers of 1.0 oz/yd^2 had a bursting strength of 24 psi compared to sample #16 having outer layers of 0.7 oz/yd^2 which displayed a busting strength value of 17.2 psi. Sample #16 having outer layers of 0.25 oz/yd^2 displayed a busting strength value of 7.8 psi. The core in all three laminates (#11, #12, and #16) was 1.0 oz/yd^2 cotton.

An increase in the weight of the cotton core was also seen to lead to an increase in the bursting strength of the laminates. Bursting strength of the laminates increased from 17.2 psi to 24.3 psi to 26.8 psi to 28.3 psi as the weight

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[2] Figures 6 through 32 are in Appendix.

Table 15. Test results of samples bonded on Kusters calender.

Sample No.	Weight		Thickness	Bursting Strength	
	(g/m^2)	(oz/yd^2)	(mm)	(psi)	(kPa)
6	153.11	4.46	0.9667	12.3	84.75
7	109.24	3.18	0.867	8.4	57.88
8	123.53	3.60	0.69	21	144.69
10	119.90	3.49	1.096	11.2	77.17
11	55.43	1.62	0.6074	7.8	53.74
12	142.39	4.15	0.86	24	165.36
13	127.02	3.70	0.79	24.3	167.43
14	167.47	4.88	0.88	26.8	184.65
15	195.04	5.68	0.93	28.3	194.99
16	98.89	2.88	0.718	17.2	118.51
17	79.46	2.32	0.571	13.7	94.39
18	159.04	4.63	0.9676	30.5	210.15
19	68.23	1.99	0.62	17.3	119.20
20	104.22	3.04	0.781	17.7	121.95
21	144.63	4.21	0.8693	20.6	141.93
22	53.77	1.57	0.4587	13.3	91.64
23	45.73	1.33	0.4529	13.0	89.57
24	21.58	0.63	0.2926	5.4	37.21
25	48.54	1.41	0.455	17.4	119.89

Table 16. Absorbent capacity by Method 1 (g/g) of laminate fabrics bonded on Kusters calender.

Sample No.	Weight Before Wetting (g)	Weight After Wetting (g)	Absorbent Capacity (g/g)
6	3.2	11.2	2.5
7	2.4	11.4	3.75
8	2.6	11.1	3.27
10	2.5	8.4	2.36
11	1.2	8.3	5.92
12	3.2	10.2	2.19
13	2.8	11.1	2.96
14	3.7	20.1	4.43
15	4.5	25.6	4.69
16	2.0	7.1	2.6
17	1.8	4.1	1.28
18	3.3	20.7	5.27
19	1.7	5.3	2.12
20	2.2	9.8	3.45
21	2.9	15.9	4.48
22	1.2	1.9	0.58
23	1.1	1.4	0.27
24	0.5	0.6	0.2
25	1.1	1.7	0.35

Table 17. Absorbent Capacity by Method 2 (ml) & Retention Capacity (ml) test results of laminate fabrics bonded on Kusters Calender.

Sample No.	Absorbent Capacity (100 Pa)[1]	Retention Capacity (3 kPa)[2]	Retention Capacity (5 kPa)[3]
6	12	10	9.5
7	9.5	9.0	8.5
8	14	12	12
10	7.0	6.0	6.0
11	8.5	8.0	8.0
12	8.5	8.0	8.0
13	11	9.5	9.0
14	14.5	12	11.5
15	17	14.5	14
16	8	7.0	6.5
17	7.5	6.5	6.0
18	18	15	14
19	7	6.5	6.0
20	12	11	11
21	17	14	13
22	4	4.0	4.0
23	7	7.0	7.0
24	8.0	7.5	7.5
25	7	7.0	7.0

1 Determined by subtracting the amount of liquid drained into the graduated cylinder at the end of 10 minutes from the original 100 ml dosage.

2 Determined by subtracting the amount of liquid unabsorbed at 3 kPa pressure from the absorption capacity.

3 Determined by subtracting the amount of liquid unabsorbed at 5 kPa pressure from the absorption capacity.

Table 18. Absorbent Capacity by Method 2(ml) & Retention Capacity (ml) test results of 100% cotton webs without being laminated to melt blown or spunbond webs.

Sample No.	Absorbent Capacity (100 Pa)[1]	Retention Capacity (3 kPa)[2]	Retention Capacity (5 kPa)[3]
1.0 oz/yd^2	24	20.5	19.5
2.0 oz/yd^2	33	20.0	19.0
3.0 oz/yd^2	34	18.5	16.5
4.0 oz/yd^2	46	23	21

1 Determined by subtracting the amount of liquid drained into the graduated cylinder at the end of 10 minutes from the original 100 ml dosage.
2 Determined by subtracting the amount of liquid unabsorbed at 3 kPa pressure from the absorption capacity.
3 Determined by subtracting the amount of liquid unabsorbed at 5 kPa pressure from the absorption capacity.

of the cotton core increased from 1.0 oz/yd^2 to 2.0 oz/yd^2 to 3.0 oz/yd^2 to 4.0 oz/yd^2 respectively.

An increase in the weight of the ramie core was also seen to lead to an increase in the bursting strength of the laminates. Bursting strength of the laminates increased from 17.3 psi to 17.7 psi to 20.6 psi as the weight of the ramie core increased from 1.0 oz/yd^2 to 2.0 oz/yd^2 to 3.0 oz/yd^2 respectively.

In Table 15, laminate fabrics made under similar conditions were seen to result in greater bursting strength when a cotton core was used as compared to a ramie core. This is particularly surprising because ramie is known as one of the strongest fibers. It should be noted that cotton in no way diminished the strength of the laminate samples (as would be expected), but is in fact enhanced the strength of the laminate fabrics compared to ramie.

Laminate fabrics which had an even lower weight SB layer compared to laminates with MB layers resulted in greater bursting strength. This can be seen by comparing sample #18 (having a 0.6 oz/yd^2 SB fabric on one side) having a bursting strength of 30.5 psi to sample #14 (having a 0.7 oz/yd^2 MB fabrics on both sides) which had a bursting strength of 26.8 psi. This may be due to the fact that the SB fabric is inherently stronger than a MB fabric.

Wicking Capacity

The wicking response curves for the laminate samples are in Figures 6 through 32 in Appendix. The higher the weight of the cotton core (keeping all the other parameters the same) in the laminate, the better the wicking performance exhibited by the laminate. This can be seen when the weight of the cotton core is raised from 1.0 to 2.0 to 3.0 to 4.0 oz/yd^2 (Samples 16, 13 , 14, 15). The

wicking response curves for these laminate samples are given in Fig. 11 through Fig. 14. The amount of water wicked in 100 seconds for the laminate samples having 1, 2, 3, and 4 oz/yd^2 of cotton was 1.1, 2.2, 3.0, and 2.6 grams and in 180 seconds was 2.5, 3.5, 3.5, and 4.5 grams, respectively. From 1 to 3.0 oz/yd^2 of cotton core weight, the amount of water wicked by the laminate samples after 100 seconds increased directly with increasing weight. However the sample with 4.0 oz/yd^2 of cotton in the core wicked less water than did the sample with 3.0 oz/yd^2 of cotton. The amount of water wicked after 180 seconds also increased proportionally to the weight, except for the sample with 3.0 oz/yd^2 of cotton which wicked to approximately the same extent as the sample with only 2.0 oz/yd^2 of cotton. These comparisons can be seen graphically in Fig. 16. The wicking capacity of laminate Sample #18 having a cotton core of 3.0 oz/yd^2 with 0.6 oz/yd^2 SB PP on one side and 0.7 oz/yd^2 MB PP on the other side is shown in Fig. 17 and is the same as Sample #21 except that it has a ramie core of 3.0 oz/yd^2 (Fig. 20). A comparison between these two laminate samples is shown in Fig. 23. From Fig. 23 it is seen that the sample having a cotton core displayed slightly higher wicking capacity as compared to the sample having a ramie core. This difference in the wicking capacity of cotton and ramie core components of the same weight may be attributed to the fact that cotton wicks a larger amount of water. Cotton's [9] excellent wicking is a result of its structure of microfibrils and its associated interstitial spaces. This gives cotton the ability to wick liquids from a surface. As can be seen from Table 15, Sample #18 also displayed higher bursting strength than Sample #21.

The wicking capacity of laminate sample #11 (having a cotton core of 1.0 oz/yd^2 and lighter 0.25 oz/yd^2 MB outside layers) in Fig. 10 was found to be better than that of sample #14 (having a cotton core of 3.0 oz/yd^2) in Fig. 13.

This increase in wicking capacity with a 1.0 oz/yd^2 cotton core was attributed to the fact that the lighter weight MB will act less as a barrier and also facilitate a quicker contact of water with the cotton core. This is an indication that lighter weight MB will lead to greater wicking even with a cotton core of lesser weight. This should prove to be good from the economic standpoint also.

Absorbent Capacity Method 1

The absorbent capacity values for Method 1 (expressed in g/g) given in Table 16 show that Sample #15 had greater absorbent capacity than Sample #14, which in turn had greater absorbent capacity than Sample #13 which in turn had greater absorbent capacity than Sample #16 (cotton core weights of 4.0, 3.0, 2.0, and 1.0 oz/yd^2 respectively). This increased absorbent capacity is probably due to the increased cotton core weight resulting in increased volume accessible (in the laminate) to the test liquid being absorbed. Cotton fiber's structure [9] and its interstitial spaces are the reasons for its excellent absorbency properties. The absorbent capacity also increased as the weight of the MB layers decreased. This can be seen in Sample #11 (which has MB outer layers of 0.25 oz/yd^2), which gave the highest absorbent capacity among all samples. The absorbent capacity of the laminate samples also was seen to increase by replacing the MB layers with SB layers, except for the best results which were obtained with the 0.25 oz/yd^2 MB PP as noted above. The SB layers are seen to increase absorbent capacity because they are less a barrier to the flow of water through them as compared to MB layers. The SB fabrics are more open in structure and have less of a cover factor when compared to MB fabrics.

The absorbent capacity of laminate Sample #18 (having a cotton core of 3.0 oz/yd^2) is seen to be better than Sample #21 (having a ramie core of 3.0 oz/yd^2), where all other laminate and processing parameters are the same. The cotton core accounted for a greater absorbent capacity than the ramie fiber core. The reason for the lower absorbent capacity exhibited by ramie is because it has more highly crystalline molecular structure - than any other cellulose fiber [29] - and constraints to swelling.

Absorbent Capacity Method 2 and Retention Capacity

As can be seen in Table 17 by reviewing Samples #13 through 16, the absorbent capacity and retention capacity were found to increase with increased cotton core weight in the laminate samples. With increased weight, there is an increase in the volume accessible to a fluid within a laminate surface accounting for the increase in absorbent capacity [7]. The increased volume accessible within a surface leads to an increase in the voids necessary to hold the fluid within a surface and, hence, accounts for greater retention capacity of the laminate samples as the cotton core weight increases. It is known that the diameter of the pores in the surface of the cotton fiber increases as the fiber becomes wet and swells. This increase in pore diameter accounts for greater and faster absorption as the test proceeds.

Cotton [9] is a highly absorbent natural fiber whose absorbency is not greatly affected by the ionic character of the liquid to be absorbed. Hence it can be used in absorbent products to absorb urine, salt solution, blood, and other body fluids as well as non-aqueous fluids.

Sample #11 (having the lighter weight MB) was found to give slightly higher absorbent and retention capacities than sample #16 (having heavier weight MB). This is an indication that lighter weight MB was better for these properties. This would also be attractive from an economical standpoint.

As seen with Absorbent Capacity Method 1, laminate fabrics having SB on one side also displayed greater absorbent capacity and retention capacity than other samples. This trend can be seen in samples #18 through 21. By comparing samples #18 (having 3.0 oz/yd^2 cotton core) and #21(having 3.0 oz/yd^2 ramie core), it was observed that the laminate having a cotton core exhibits both better absorbent capacity and retention capacity . This also shows that the usage of SB fabric is economically advantageous because with lower weight core (3.0 oz/yd^2) sample #18 displayed slightly higher absorbent and retention properties than sample #15 (4.0 oz/yd^2 cotton and MB PP on both sides). The usage of SB fabric also provides the laminate its excellent mechanical properties.

Overall it is seen that a cotton core contributes to higher absorbent and retention properties than ramie core. The reason for this may be due to the fact that ramie has a more highly crystalline molecular structure than other cellulosic fibers [29]. Since water is absorbed primarily in the less ordered regions, the highly crystalline molecular structure of ramie may make it less effective for absorption, although ramie would appear to be an acceptable substitute for cotton for wicking, absorbency and retention performance if its economic advantages and/or availability are better than cotton.

From the discussion of the wicking, absorbent capacity and retention capacity test results, it is clear that the usage of cotton in the core of the laminate is beneficial in the applications for which these products are being made. In order to confirm our results, samples having only MB layers (without the cotton core)

and only cotton webs (of the same weight as those used in the laminates) were made and tested for their wicking capacity, absorbent capacity, and retention capacity. This was done to observe the individual influences of the MB layers and cotton webs when one was used without the other.

The wicking response curves for Laminate Samples #22 through 25 display very poor wicking. The reason for this was probably the hydrophobic nature of the MB layers of polypropylene. These MB layers when used with a cotton web in between them displayed much greater wicking. The wicking was also seen to increase with an increase in the weight of the cotton core. In stark contrast to the Samples #22 through 25 were the cotton webs (from 1.0 to 4.0 oz/yd^2) - without being laminated to MB or SB webs - that displayed an increasing trend of wicking response. This shows that cotton webs are responsible for the wicking response displayed by the laminate samples.

The Laminate Samples #22, 23, 24 and 25 displayed very low absorbent capacity by Method 1 (Table 16), although the absorbent capacity by Method 2 and retention capacity as is seen from Table 17 were better than would be expected. The latter may be explained by the fact that the MB webs retain the water by holding a pocket of water between the two webs, although the water would not be held within the MB webs which is confirmed by the extremely low absorbency obtained by Method 1. The cotton webs (from 1.0 to 4.0 oz/yd^2), without being laminated to MB or SB webs, exhibited excellent absorbent capacity and good retention capacity as seen from Table 18. The absorbent capacity of the cotton webs increased as its weight was increased. This was not the case with retention capacity values. At this point it is interesting to recall that these cotton webs when incorporated in a laminate structure gave increased absorbent capacity and retention capacity in proportion to core weight. It should

again be noted that cotton was very dominant in influencing the absorbent and retention capacity of the laminate samples and thereby justifies its usage in these products.

Effect of different polymers

In comparing the effects of using melt blown webs of different polymers, it can be seen in Tables 15, 16, and 17 that both Ethylene Vinyl Acetate (EVA) and Ethylene Methyl Acrylate (EMA) co polymers and Linear Low Density Polyethylene (LLDPE) resulted in lower bursting strength, even at greater basis weight than did 1.0 oz/yd^2 MB polypropylene (PP) webs. As was noted in Table 5, because these polymers have lower softening and melting points, lower bonding roller temperatures and lower nip pressure (except for LLDPE nip pressure) were utilized during calendering to avoid melting of the webs and sticking to the calender rolls. The nylon 6 MB webs when used as the outer layers on both sides of the cotton core resulted in similar bursting strength of 21 psi compared to 24 psi with the 1.0 oz/yd^2 MB PP webs. Although the PET and PBT samples # 9A and 9B resulted in well bonded laminates, the quantity produced was insufficient for testing.

The absorbent capacity by method 2 of sample #7 produced with EMA MB webs was in the same range as sample #12 with 1.0 oz/yd^2 MB PP webs, and sample #6 produced with EVA webs was greater at 12.0 ml compared to 8.5 ml for sample #12. The retention capacity values of these samples followed the same trends. On the other hand, samples # 6 and 7 produced with EVA and EMA respectively had greater wicking capacity of 3.2 g and 6.2 g compared to 0.4 g

with sample #12. Likewise, nylon 6 MB webs used in sample #8 displayed notably greater absorbent, retention, and wicking capacities than sample #12.

CHAPTER 6

CONCLUSIONS

In the development of thermally bonded laminates with novel binder fabrics with natural fibers for medical and personal hygiene applications it has been observed that the process parameters of the components need to be maintained in such a way that the resultant products have the physical properties necessary to meet the demands of the medical nonwovens. The findings of the present study are summarized as follows:

Part A: Barrier properties of MSM laminates

Several of the parameters appeared to have a major effect on the properties of the laminates developed in Part A. The more notable ones are stated below:

1. The weight of the melt blown fabric used as the outer layer appeared to result in a change of air permeability and strength properties of the MSM laminate fabrics. Decreasing the basis weight of the melt blown fabric appeared to increase the air permeability of the MSM laminates. Also decreasing the basis weight of the melt blown web resulted in decreased strength properties which may be attributed to a smaller amount of melt blown web for thermal bonding the laminate as well as for providing load bearing support. As would be expected, the use of lighter weight melt blown webs appeared to result in decreased bending length.
2. The fluorochemical finish provided excellent barrier properties such as repellency to water, oil, and alcohol by lowering the critical surface energy of the treated nonwoven substrate below that of the wetting liquid.

Part B: Absorbency properties of laminates

The parameters that appeared to have an effect on the properties of the laminates developed in Part B were the following:

1. The weight of the cotton core appeared to have a notable effect on the wicking, absorbent capacity, and retention capacity of the product. The irregular cross-sectional shape and surface texture of cotton may be responsible for the aforementioned properties. The cotton core component appeared to contribute toward better wicking, absorbent capacity, and retention capacity of the product as compared to a ramie core component. It was theorized that the presence of highly crystalline regions in ramie could be responsible for the lower wicking, absorbent capacity, and retention capacity values. The laminate fabrics that did not have any cotton or ramie web in the core between the melt blown or spunbond webs displayed very poor wicking, absorbent capacity, and retention capacity. This demonstrated the real value of cotton in these products.
2. The use of spunbond fabric appeared to result in higher strength, better wicking, absorbent capacity, and retention capacity of the product as compared to the use of melt blown fabric. The spunbond fabrics being inherently stronger contributed to the higher strength of the laminates. The high void content of the spunbond fabric most likely contributed to better wicking, absorbent , and retention capacities compared to similar weight melt blown fabrics.
3. The use of a lighter weight melt blown fabric appeared to result in greater wicking capacity as compared to a heavier weight melt blown fabric which may be attributed to the reduced barrier properties of the lighter weight melt blown web.

Recommendations for future work

1. Improve the strength of the laminates by incorporating a spunbond layer.

2. Evaluate the use foam finishing techniques in an effort to better control finish penetration and possibly use less finish. Foam finishing should also reduce energy consumption by reducing the wet pickup.
3. Explore the use of laminates of natural fibers with melt blown and spunbond webs in other product applications.
4. Study the comfort properties of these laminates using instrumental techniques such as the Kawabata Evaluation System as well as conducting wearing comfort studies.
5. Work with the nonwovens industry as well as with hospitals and consumers to further develop and evaluate laminates of natural fibers with melt blown and spunbond webs for use as operating room apparel, absorbent pads and diapers.

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APPENDIX

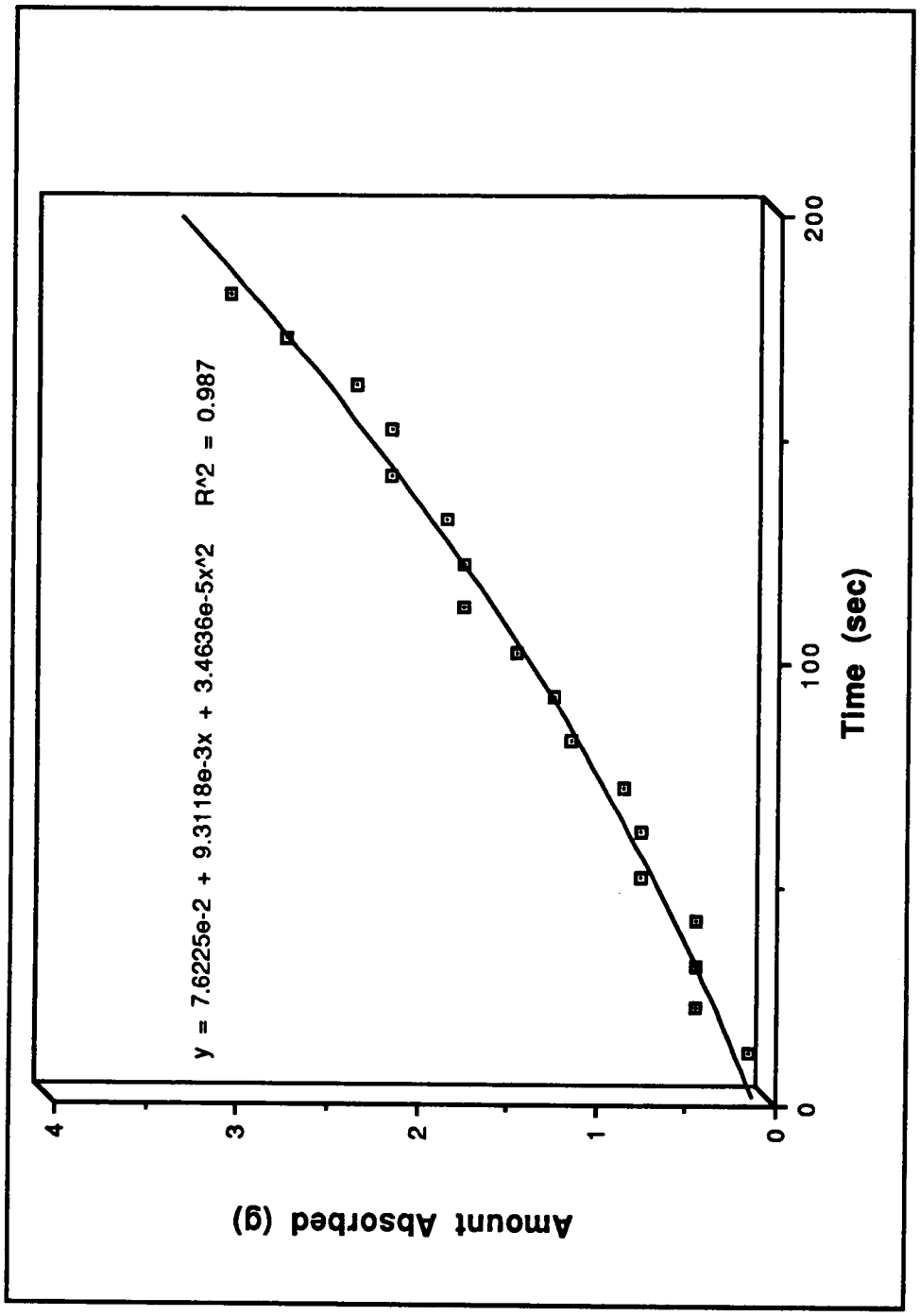


Fig. 6 -- Wicking response curve for Sample #6.

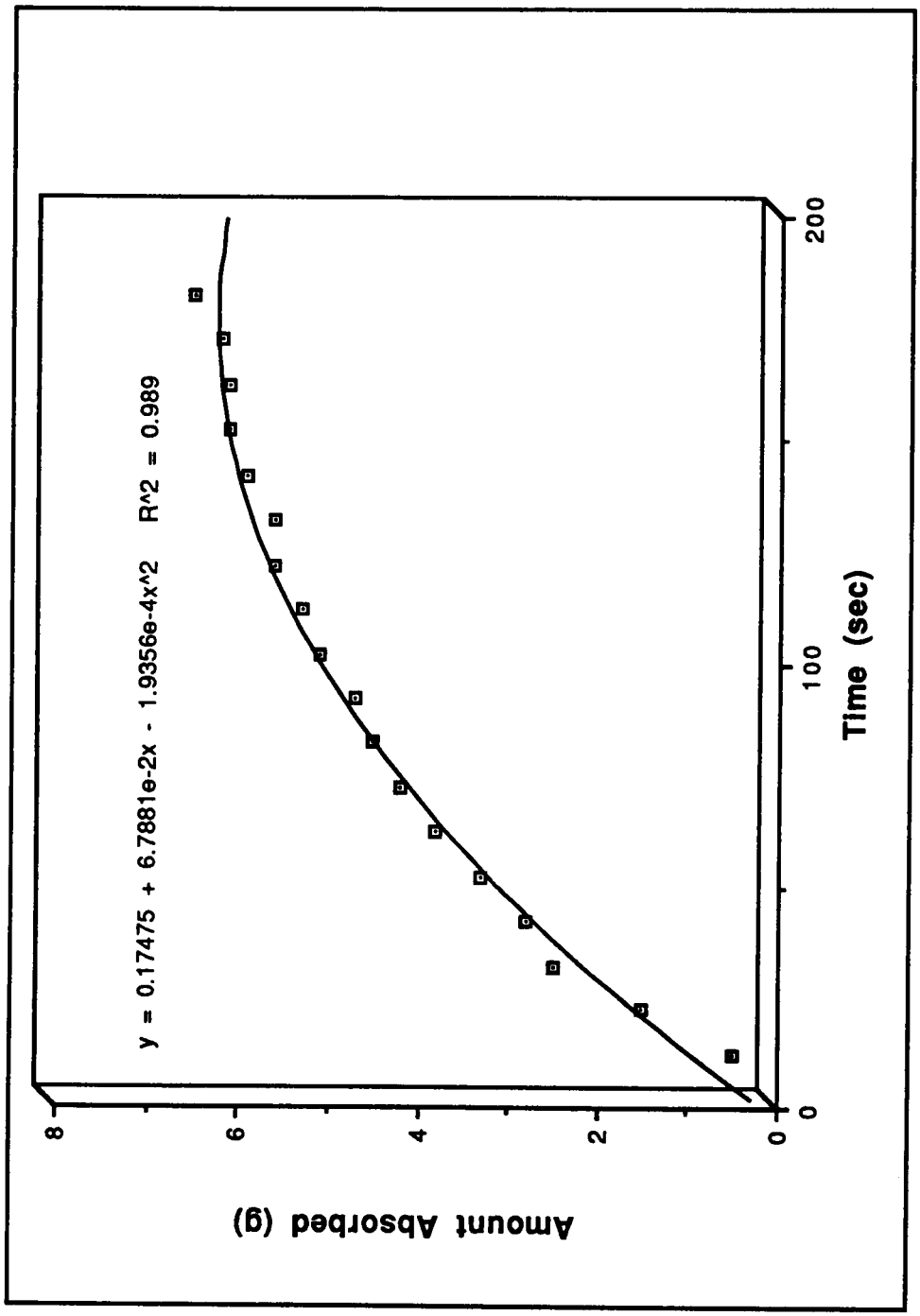


Fig. 7 -- Wicking response curve for Sample #7.

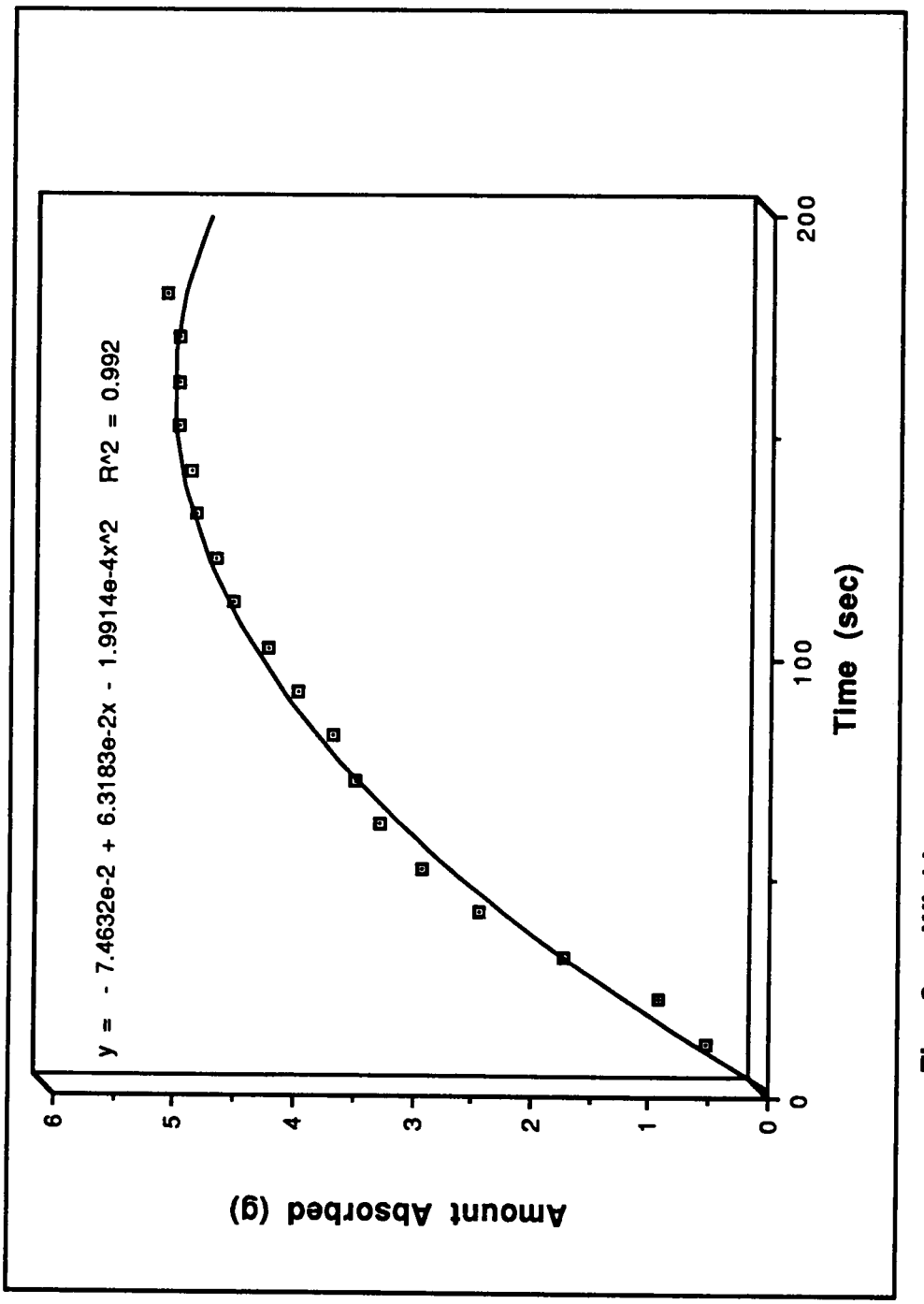


Fig. 8 -- Wicking response curve for Sample #8.

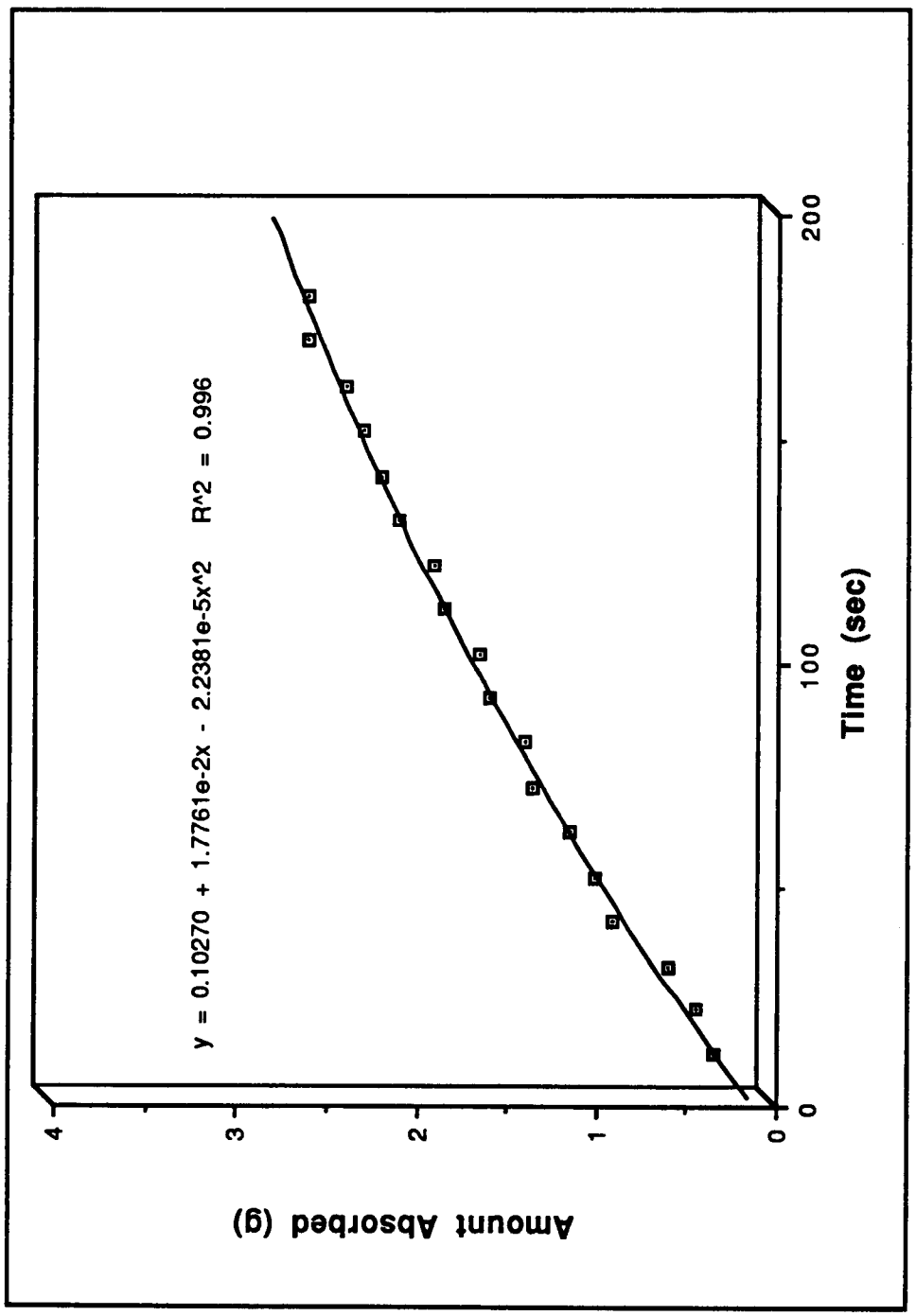


Fig. 9 -- Wicking response curve for Sample #10.

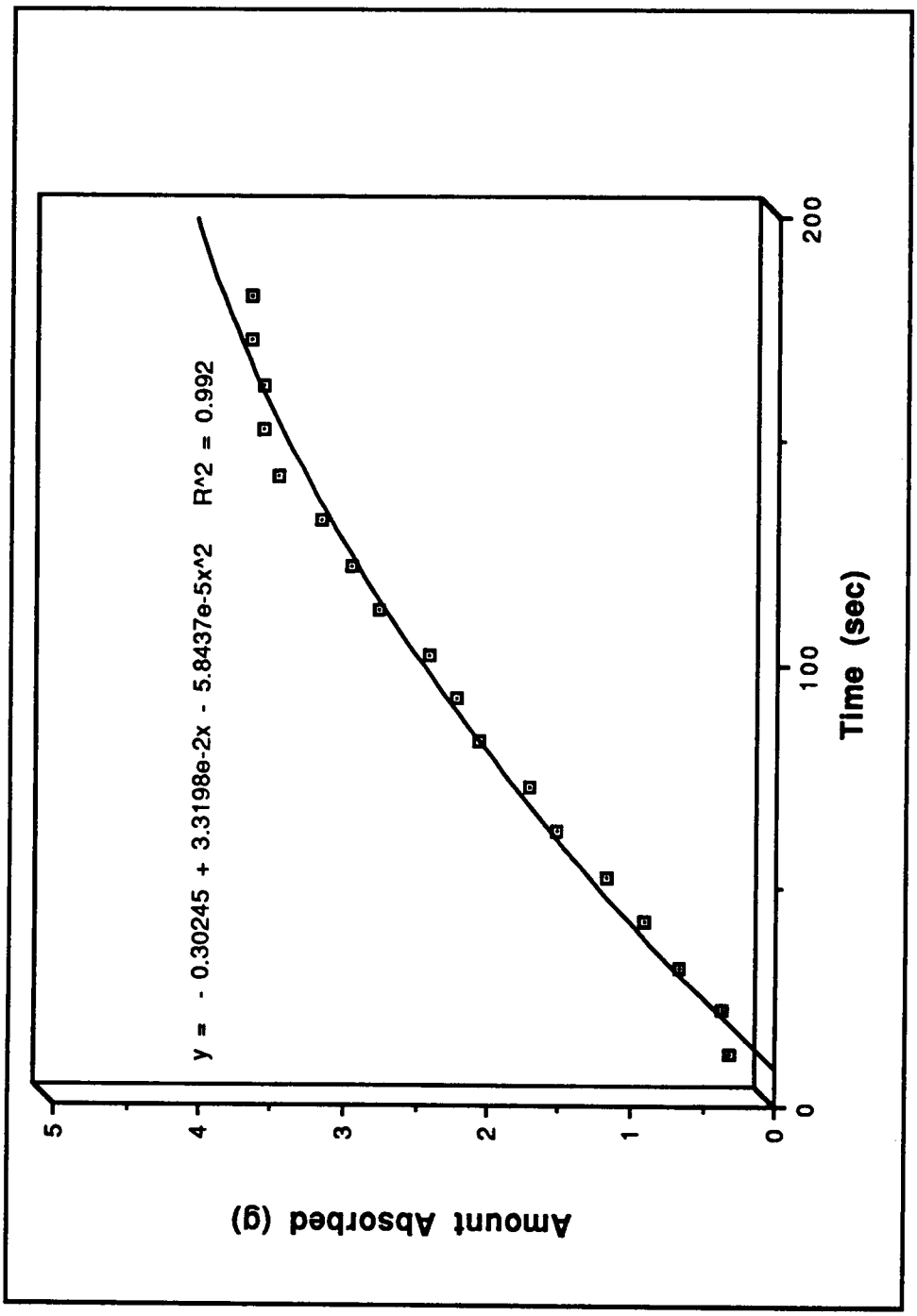


Fig. 10 -- Wicking response curve for Sample #11.

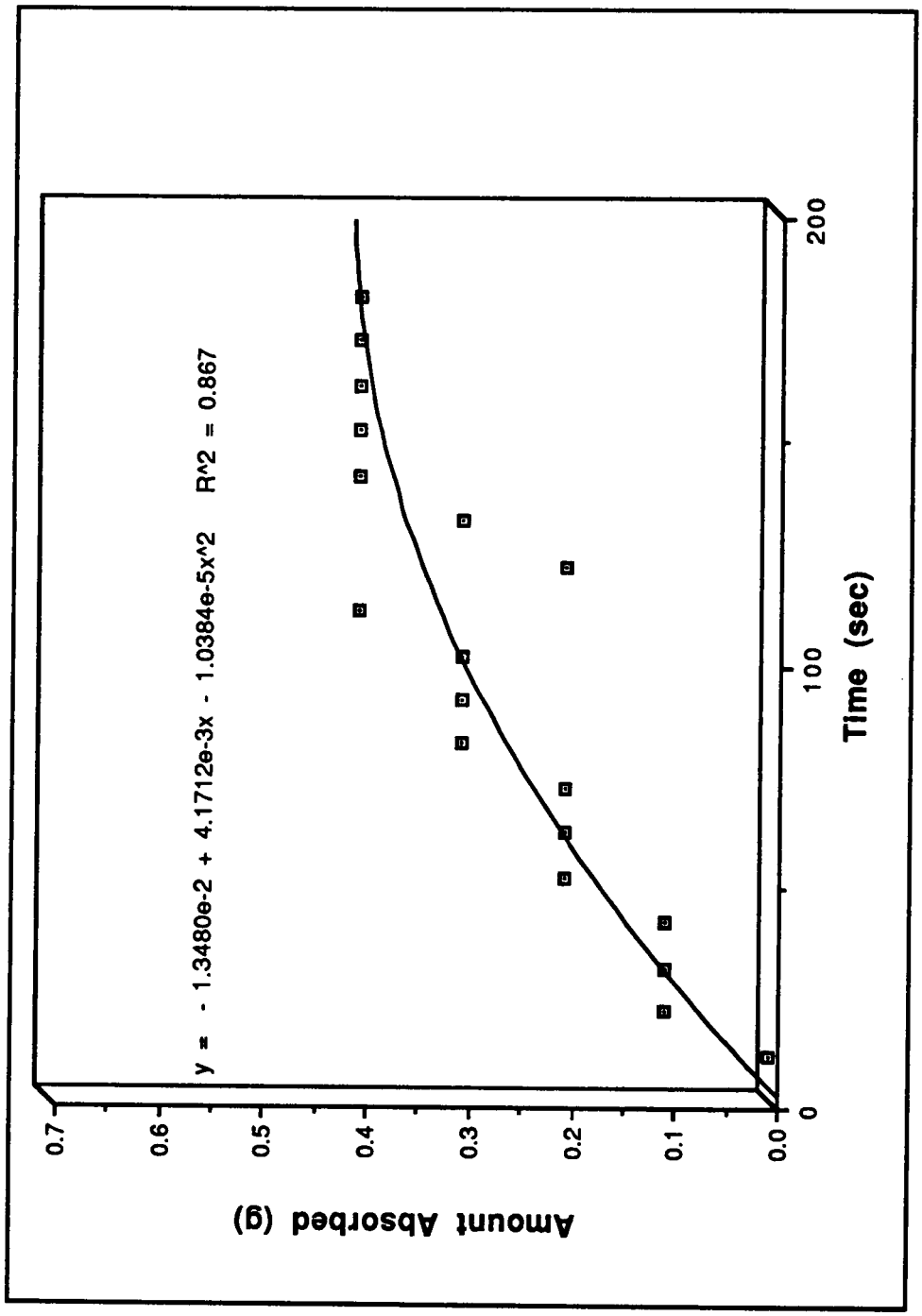


Fig. 11 -- Wicking response curve for Sample #12.

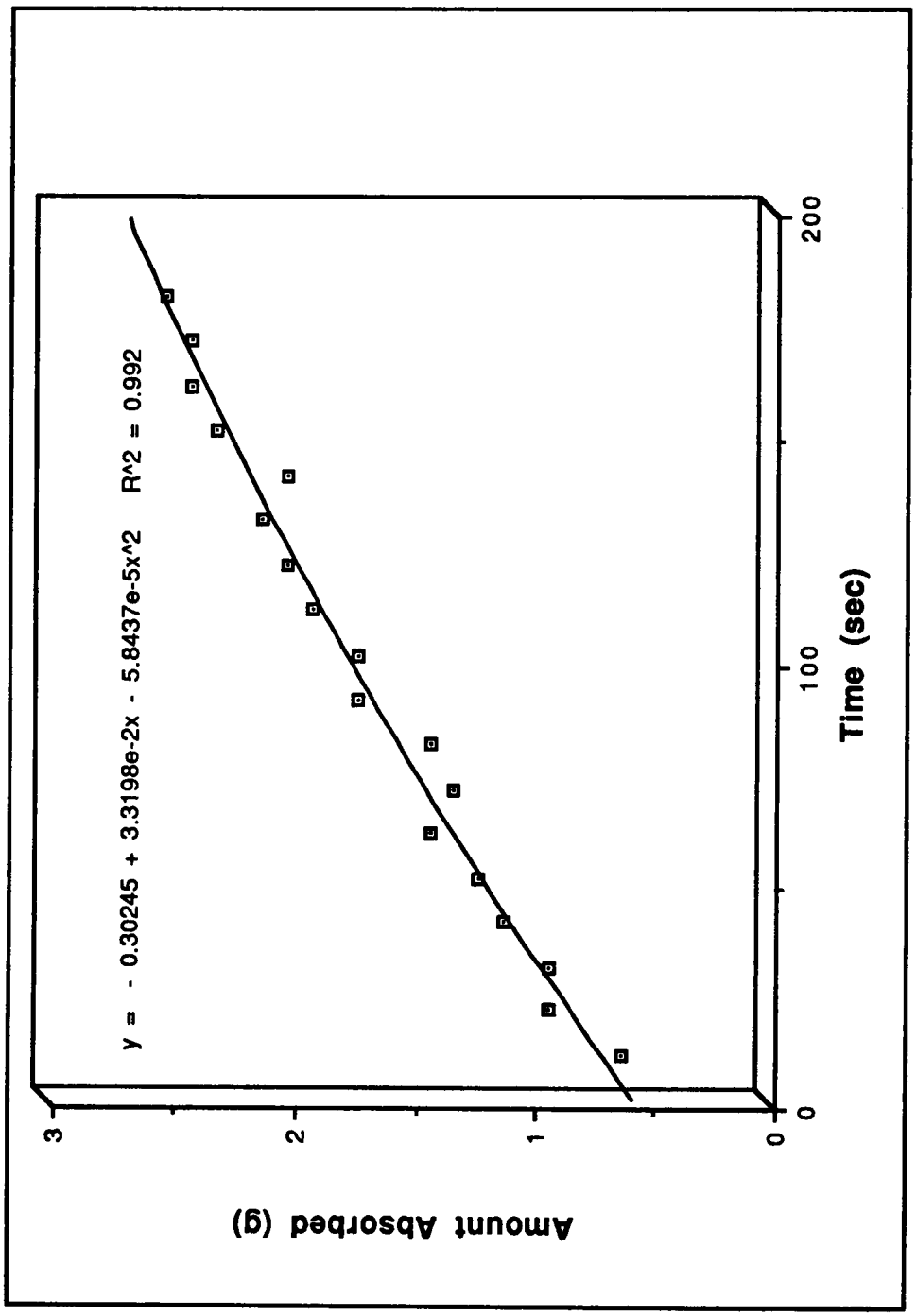


Fig. 12 -- Wicking response curve for Sample #16.

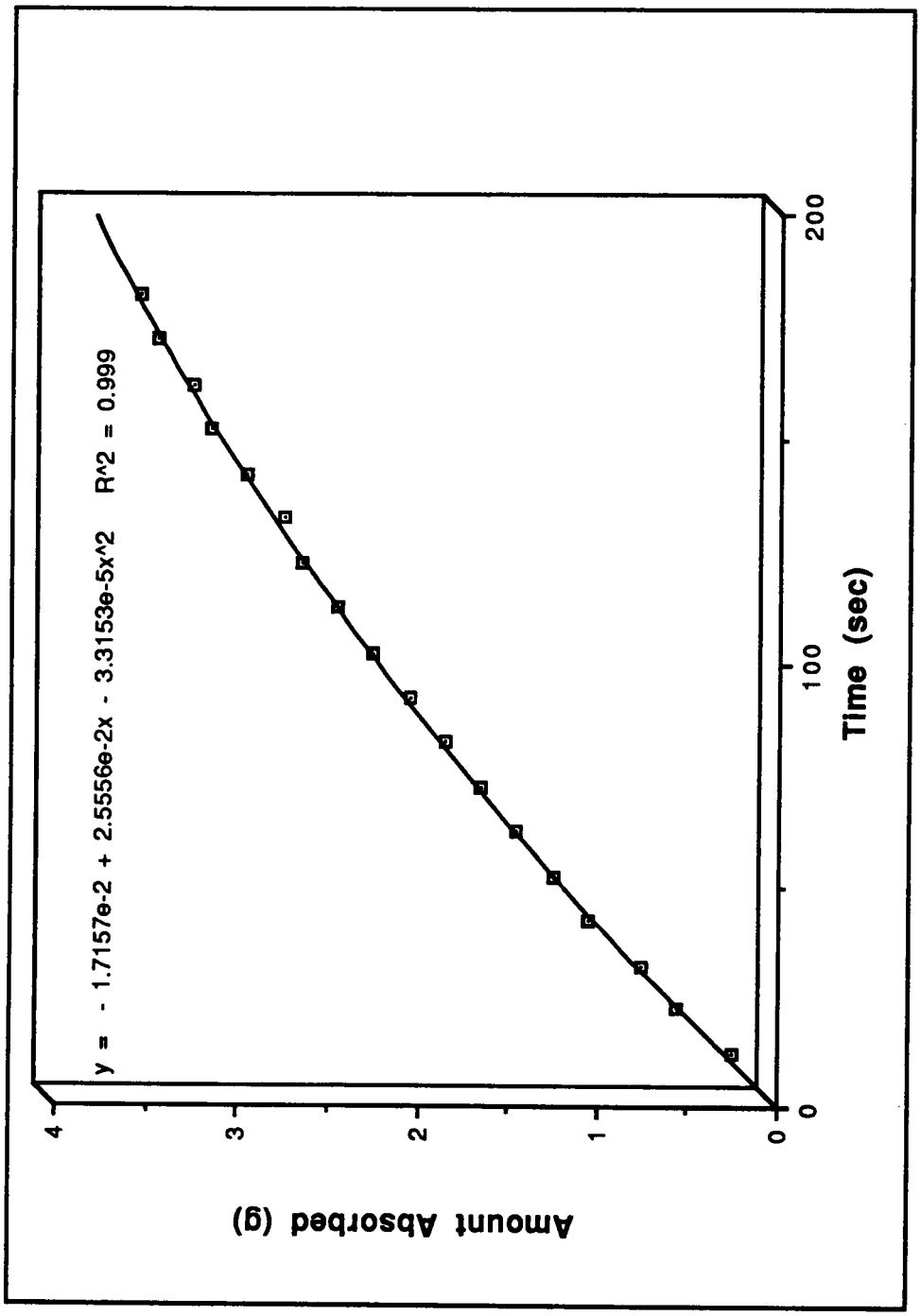


Fig. 13 -- Wicking response curve for Sample #13.

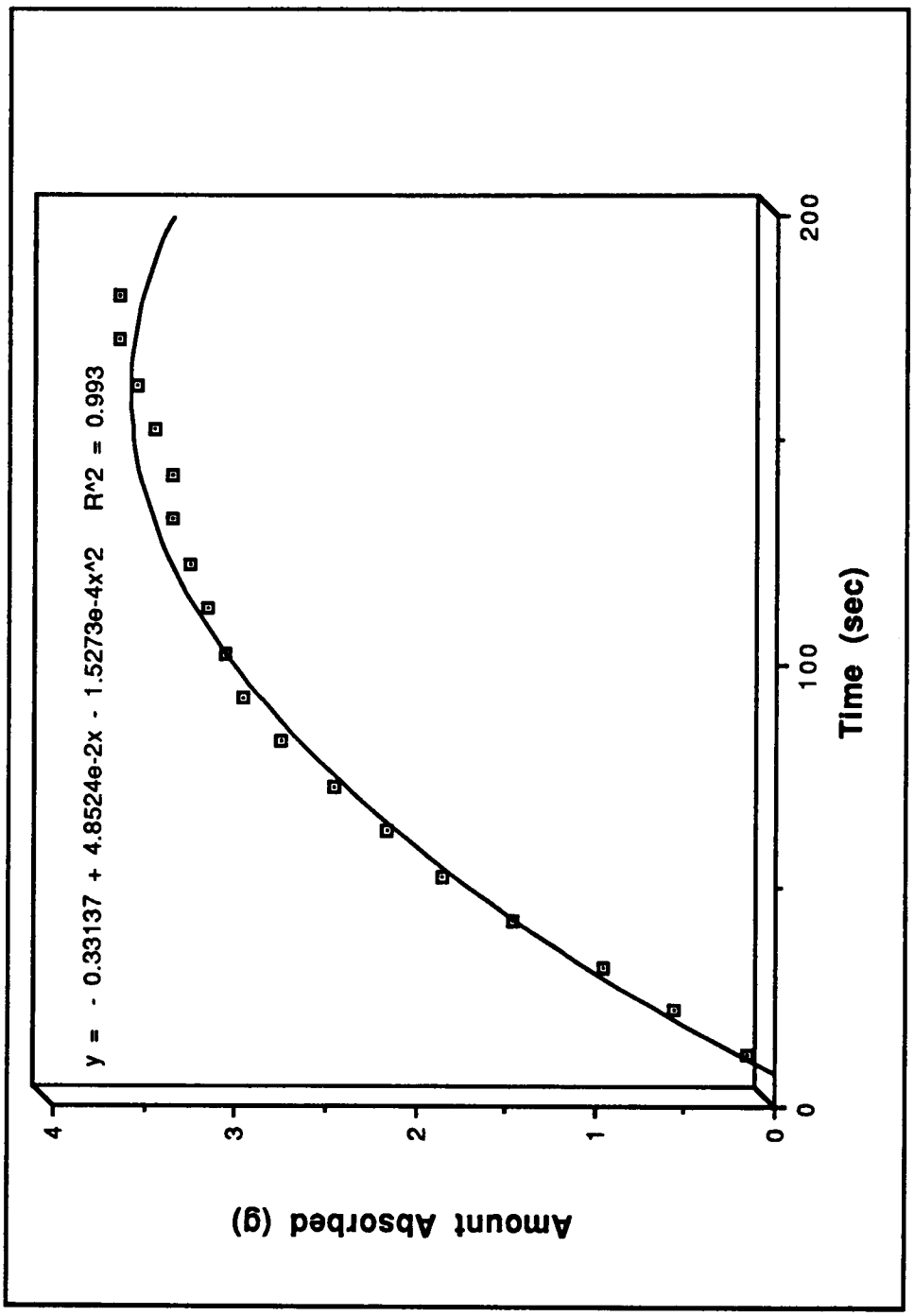


Fig. 14 -- Wicking response curve for Sample #14.

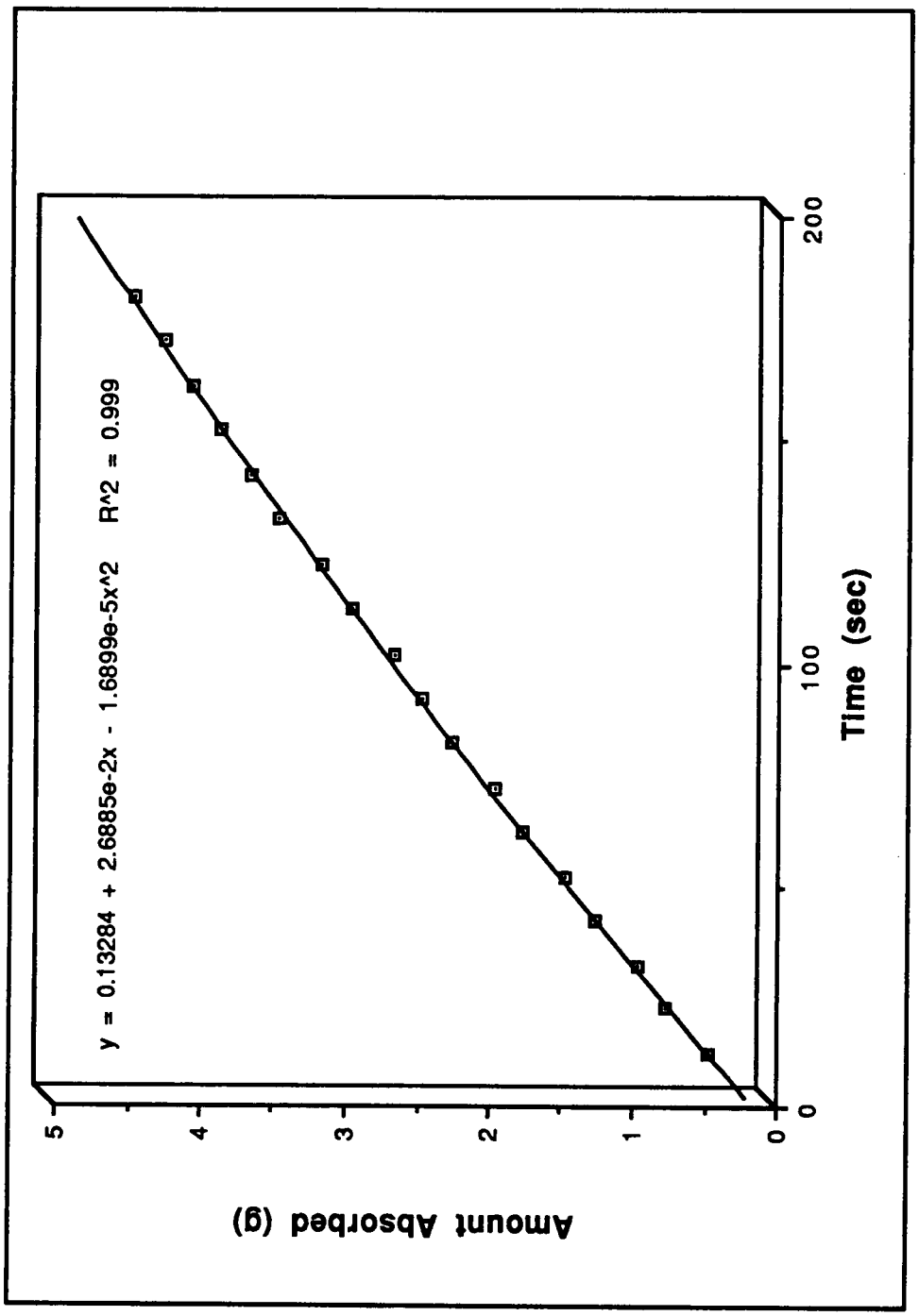


Fig. 15 -- Wicking response curve for Sample #15.

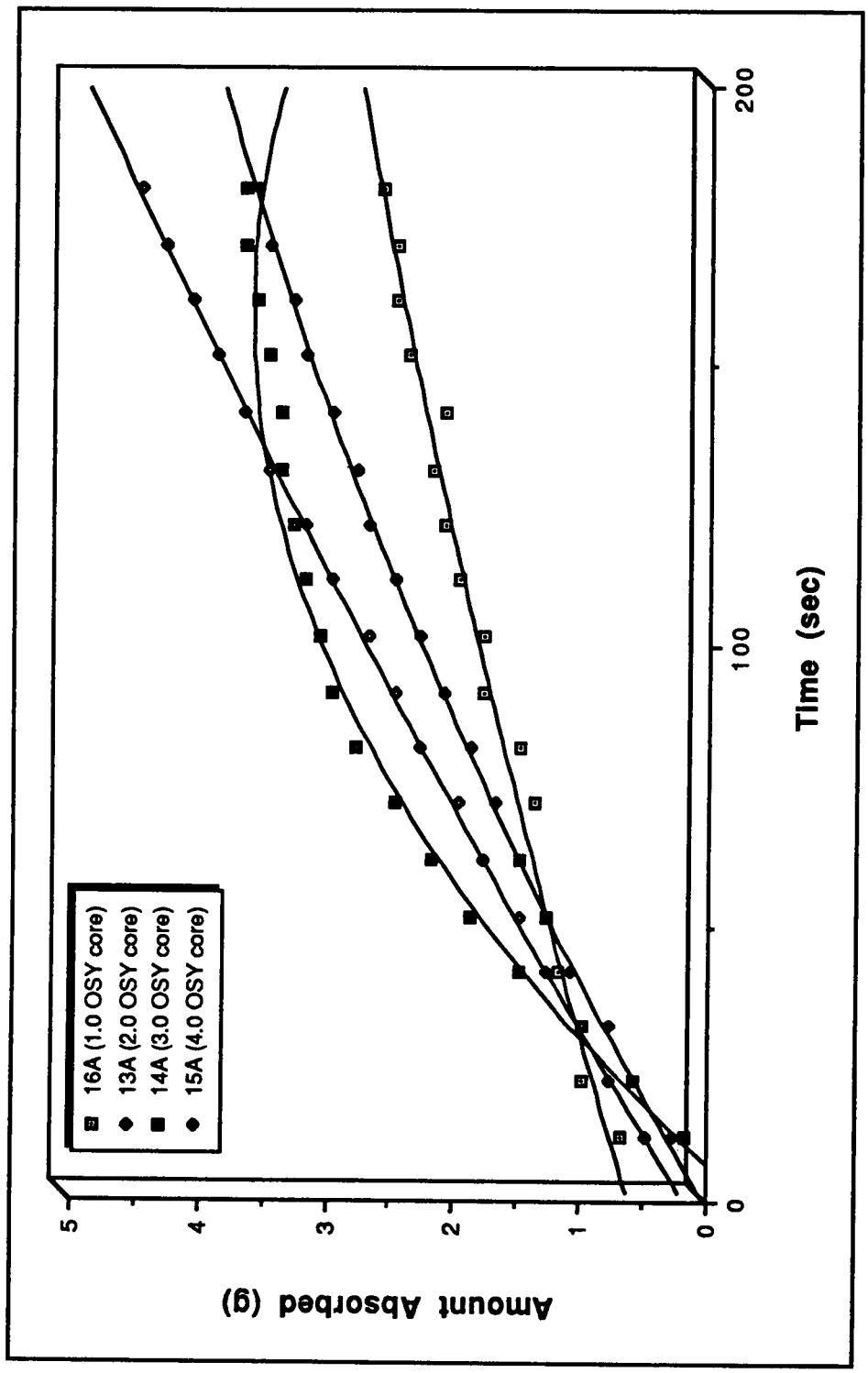


Fig. 16 -- Wicking response curves for fabrics with different cotton core weight.

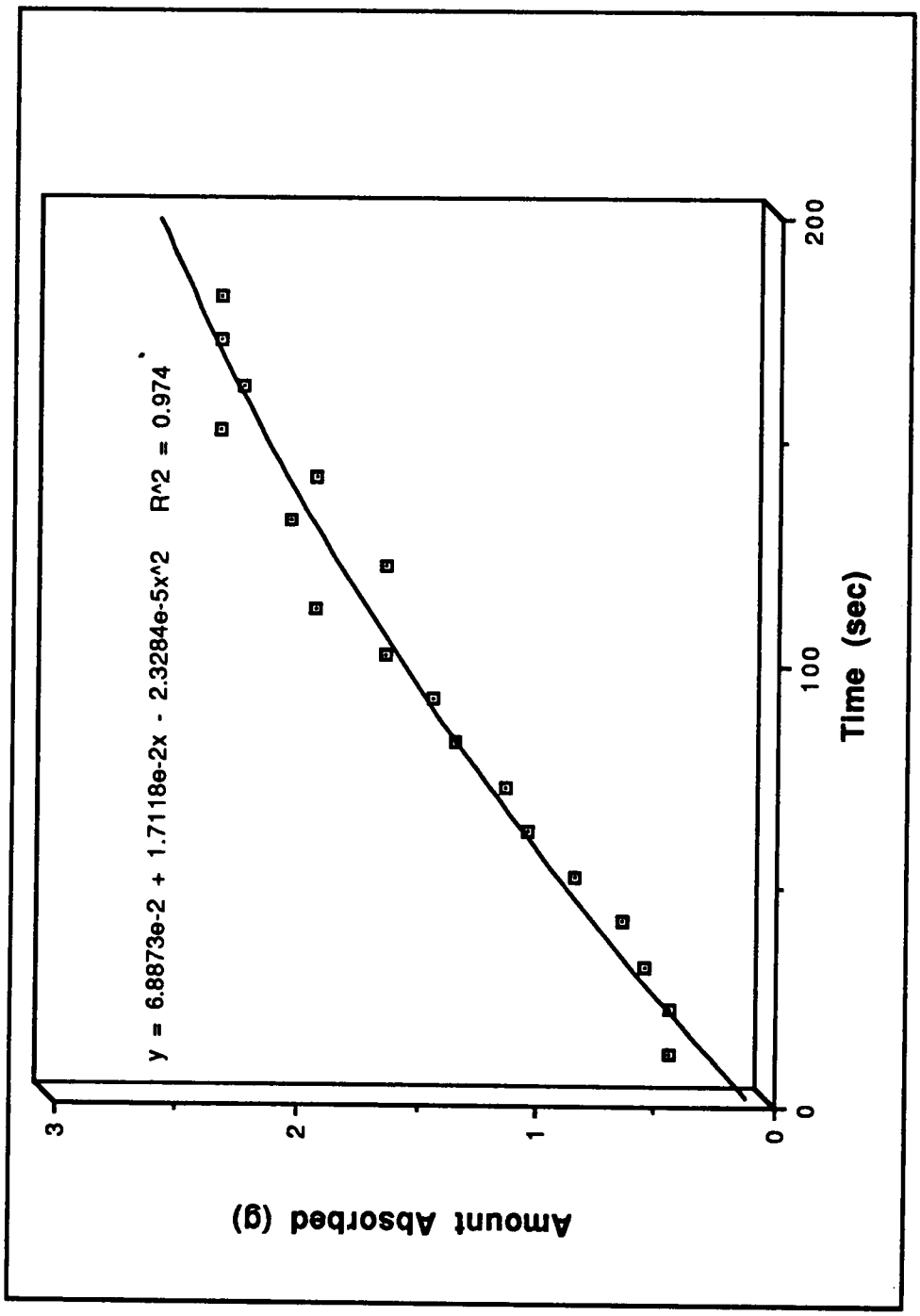


Fig. 17 -- Wicking response curve for Sample #17.

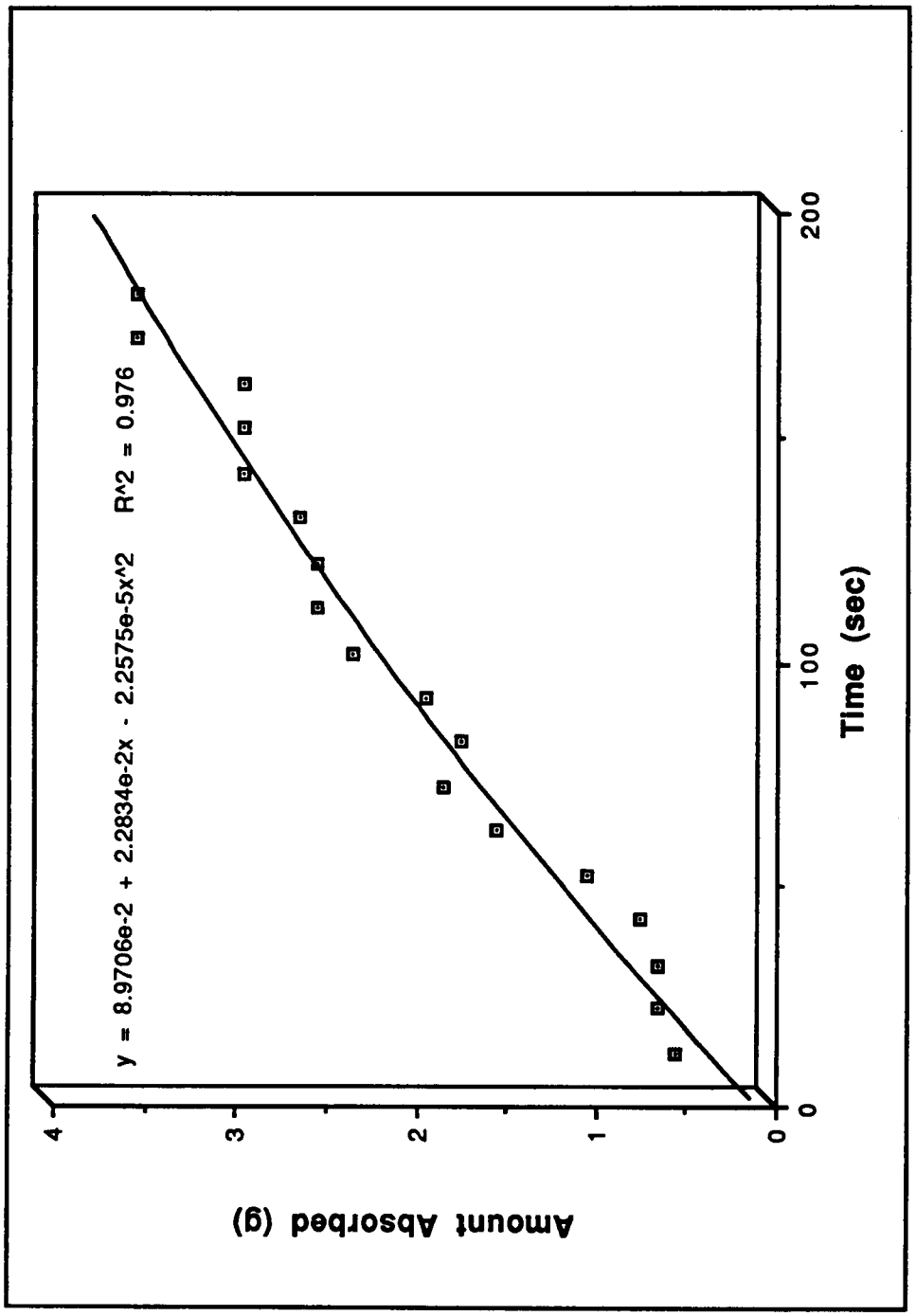


Fig. 18. -- Wicking response curve for Sample #18.

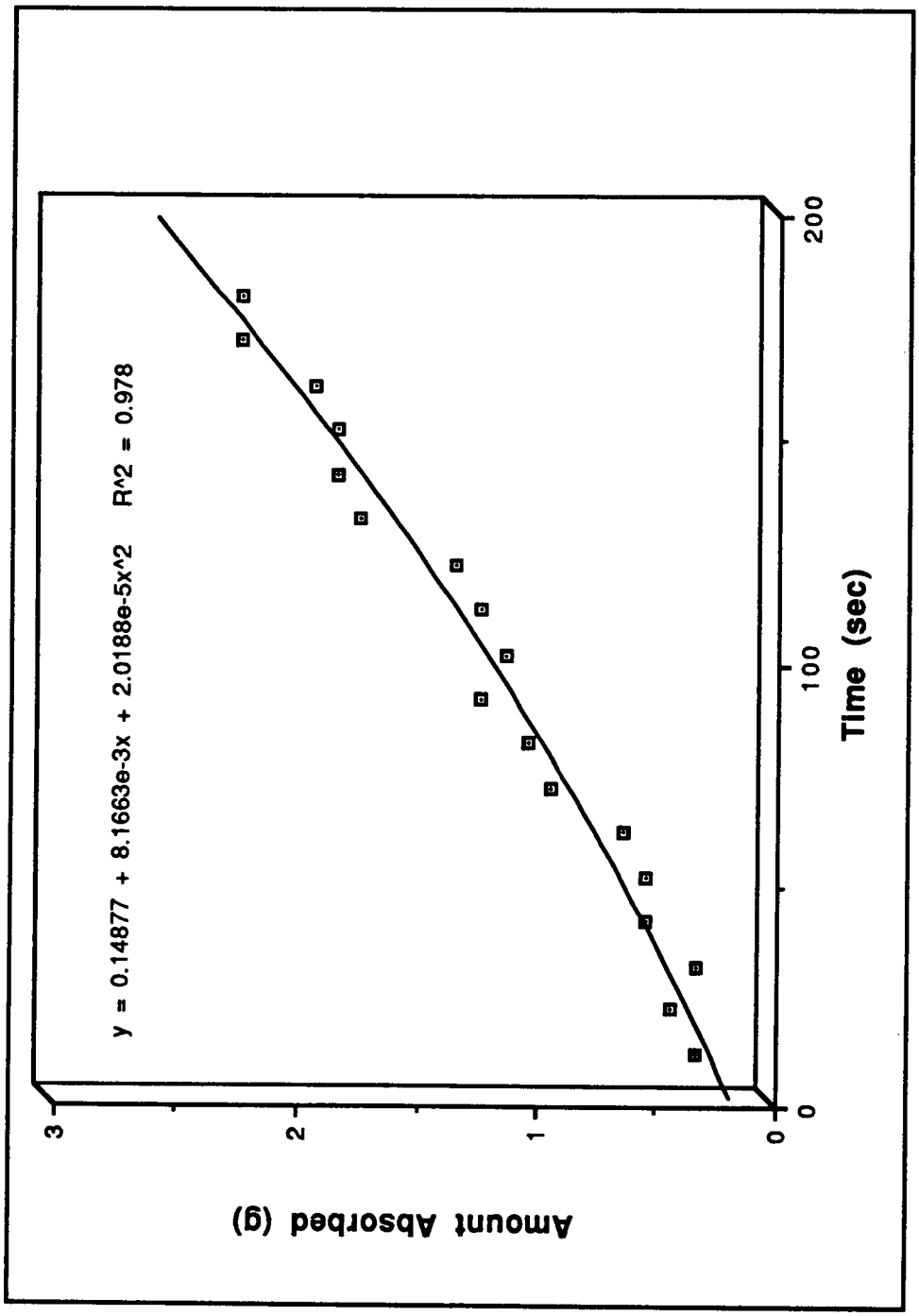


Fig. 19 -- Wicking response curve for Sample #19.

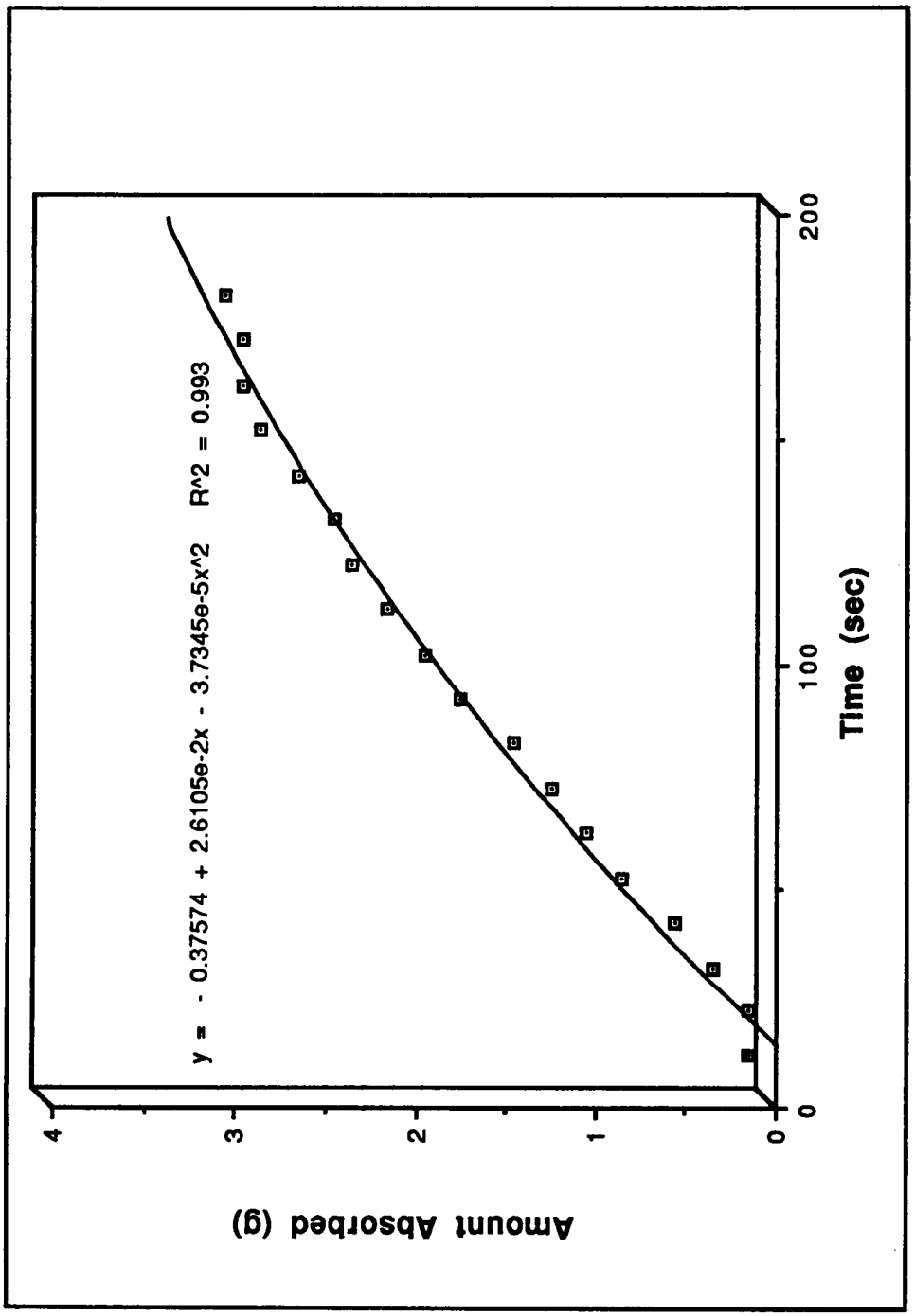


Fig. 20 -- Wicking response curve for Sample #20.

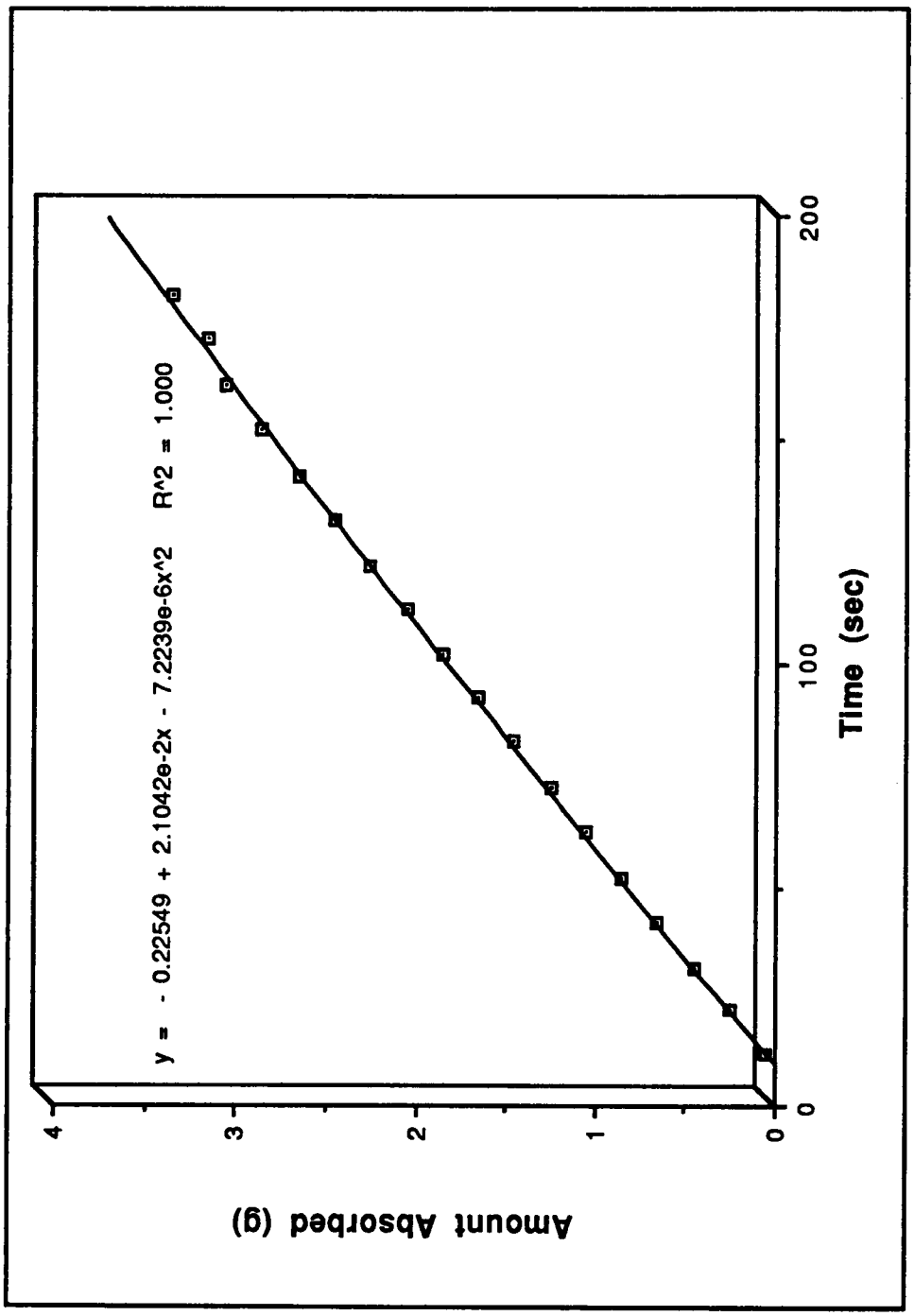


Fig. 21 -- Wicking response curve for Sample #21.

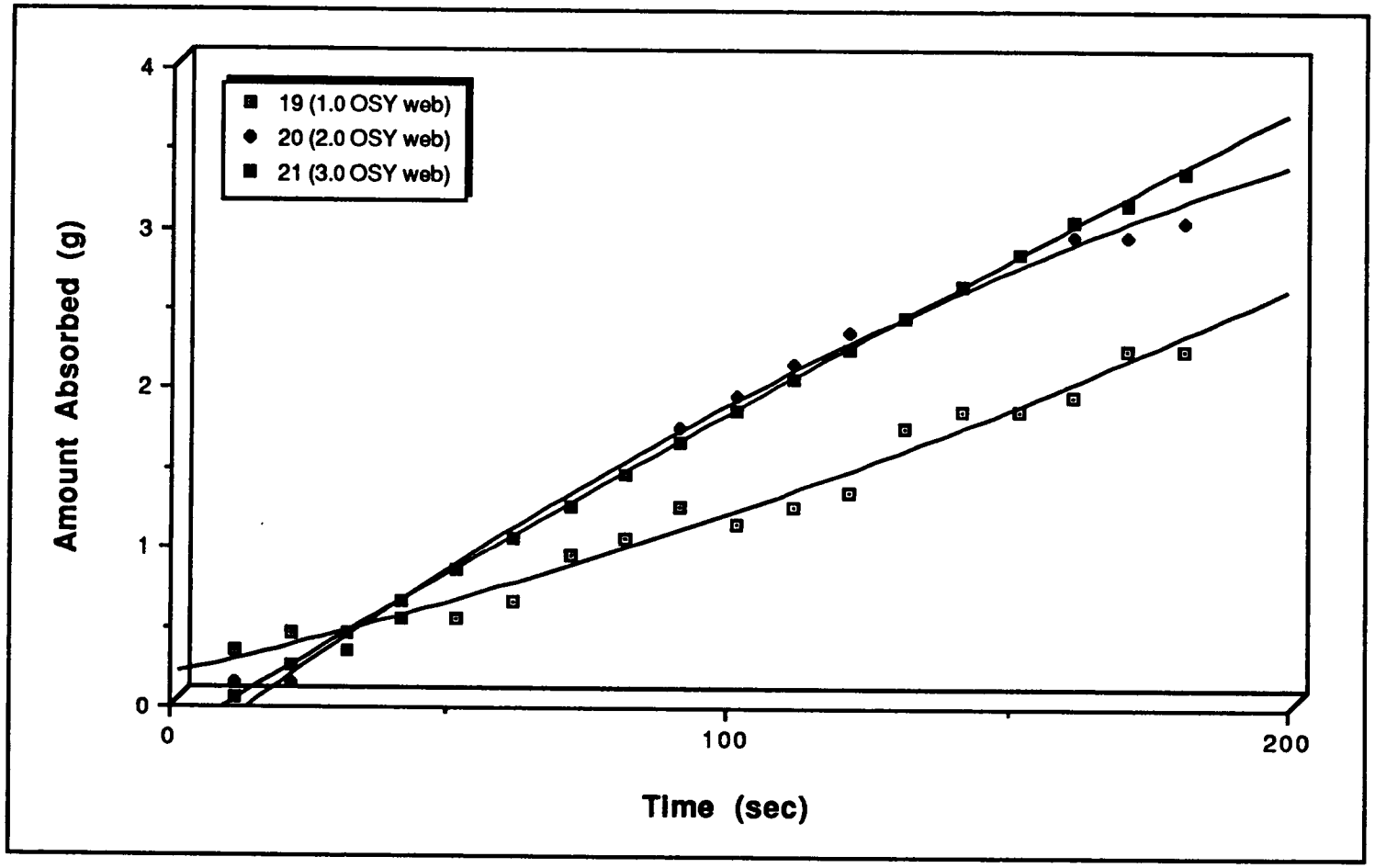


Fig. 22 -- Wicking response curves for fabrics with different ramie core weights.

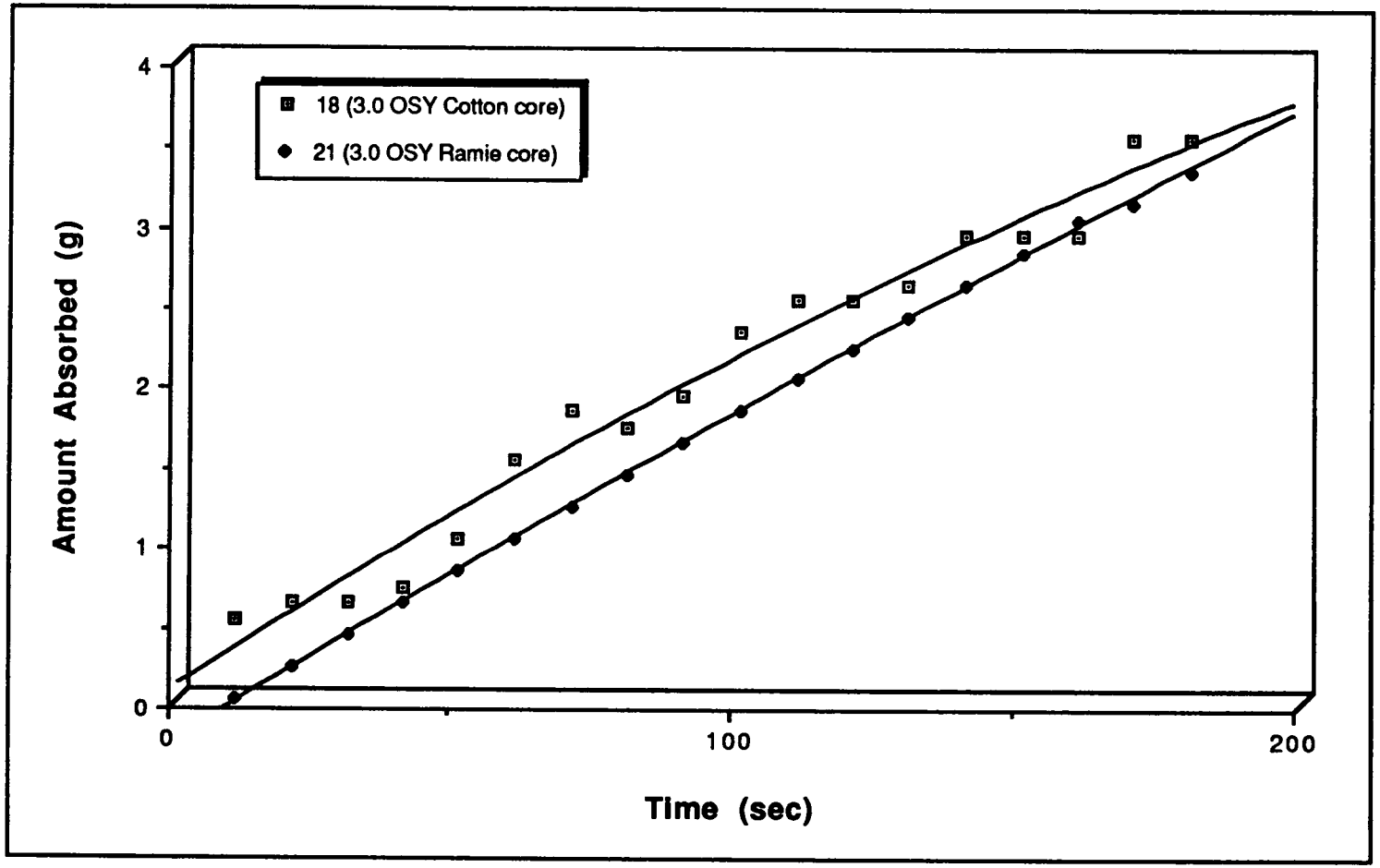


Fig. 23 -- Wicking response curves for fabrics with cotton and ramie core components.

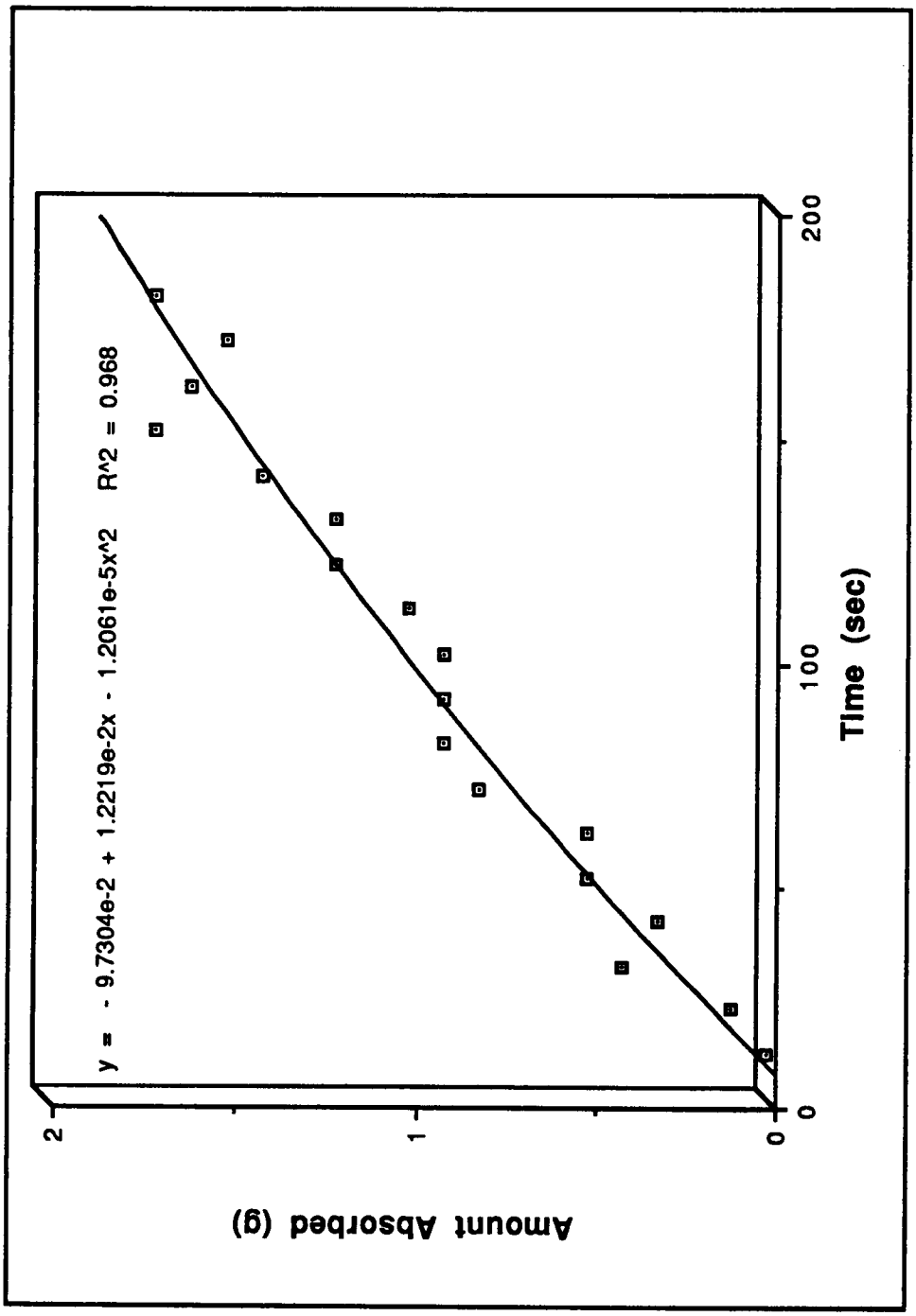


Fig. 24 -- Wicking response curve for Sample #22.

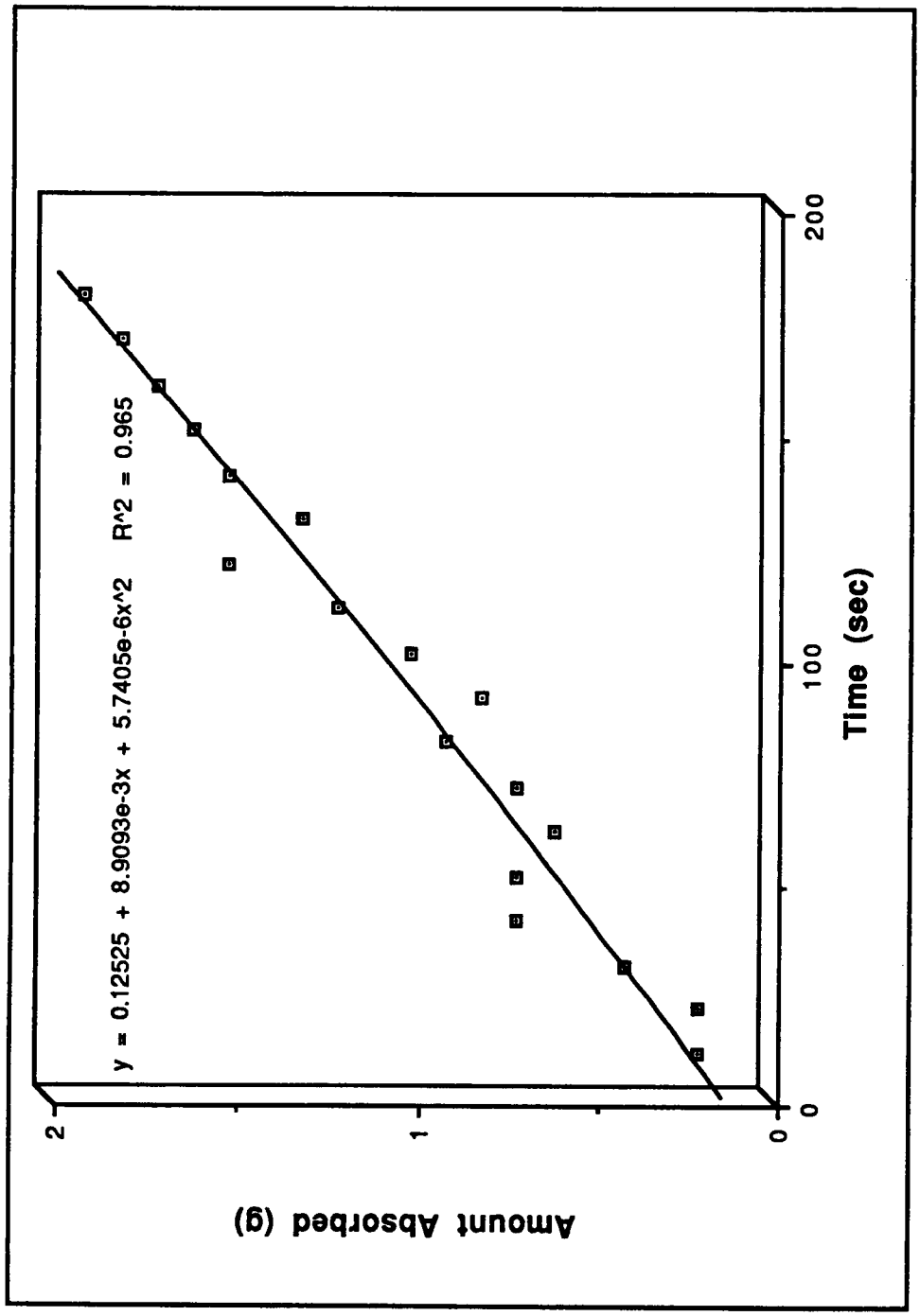


Fig. 25 -- Wicking response curve for Sample #23.

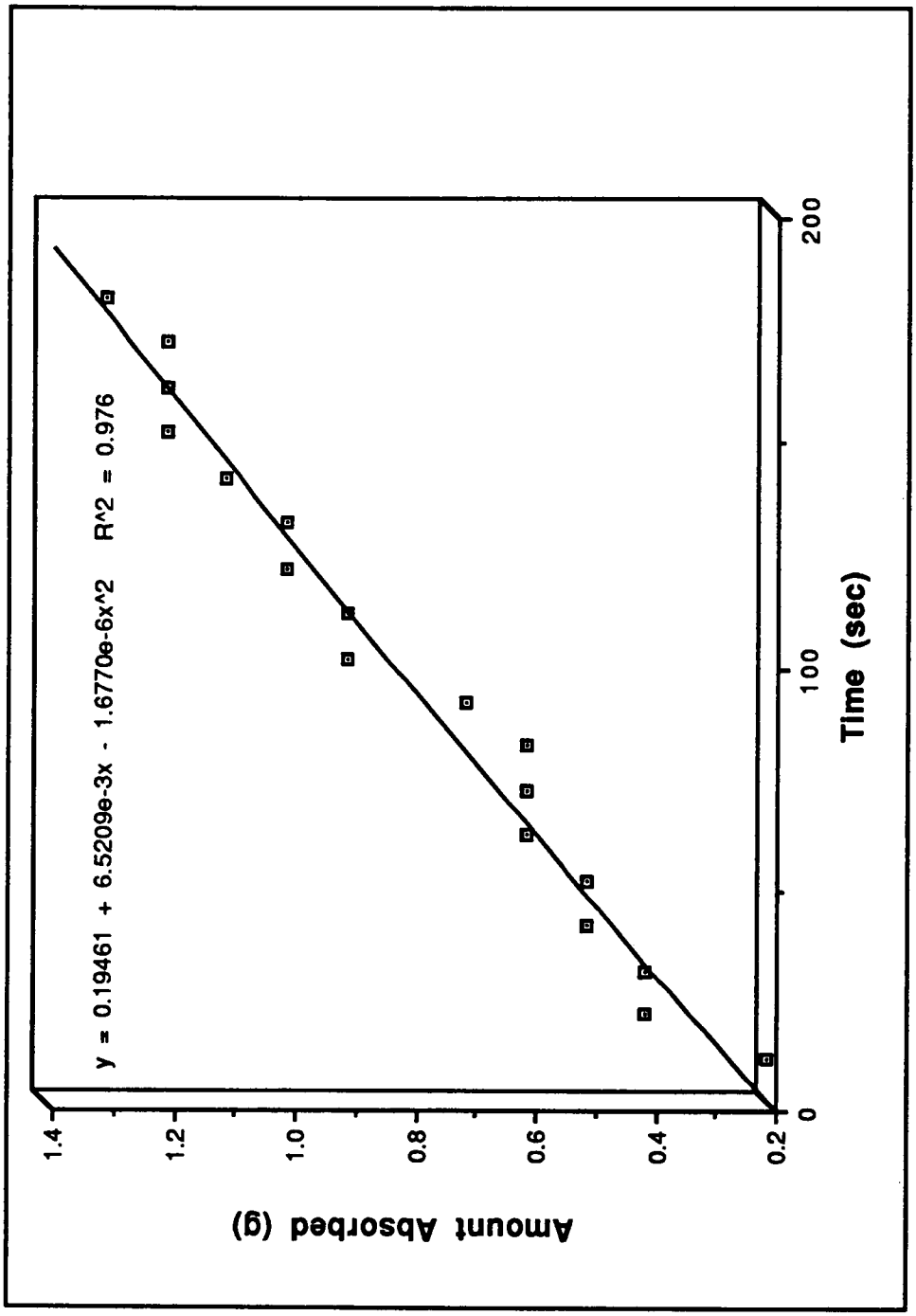


Fig. 26 -- Wicking response curve for Sample #24.

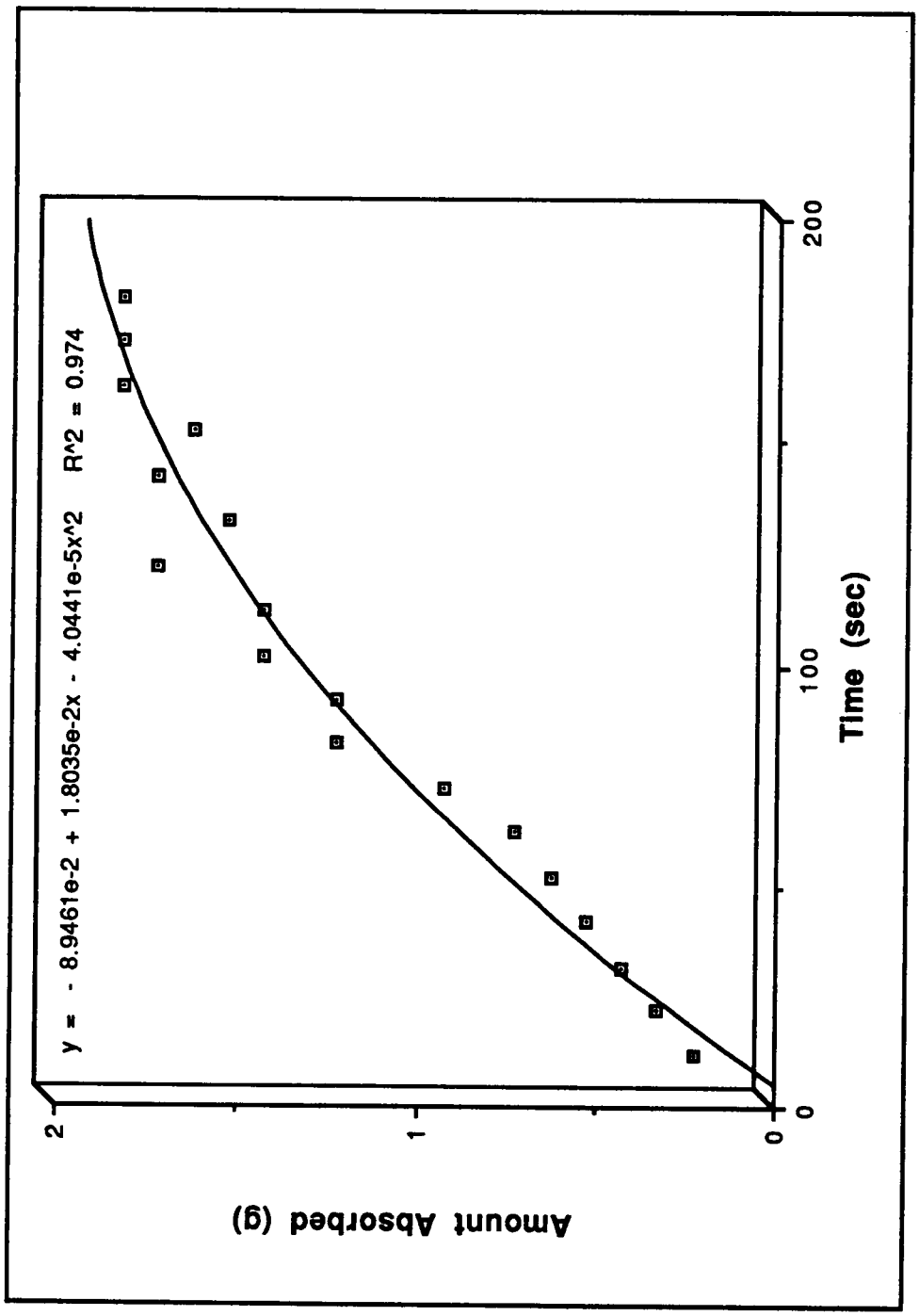


Fig. 27 -- Wicking response curve for Sample #25.

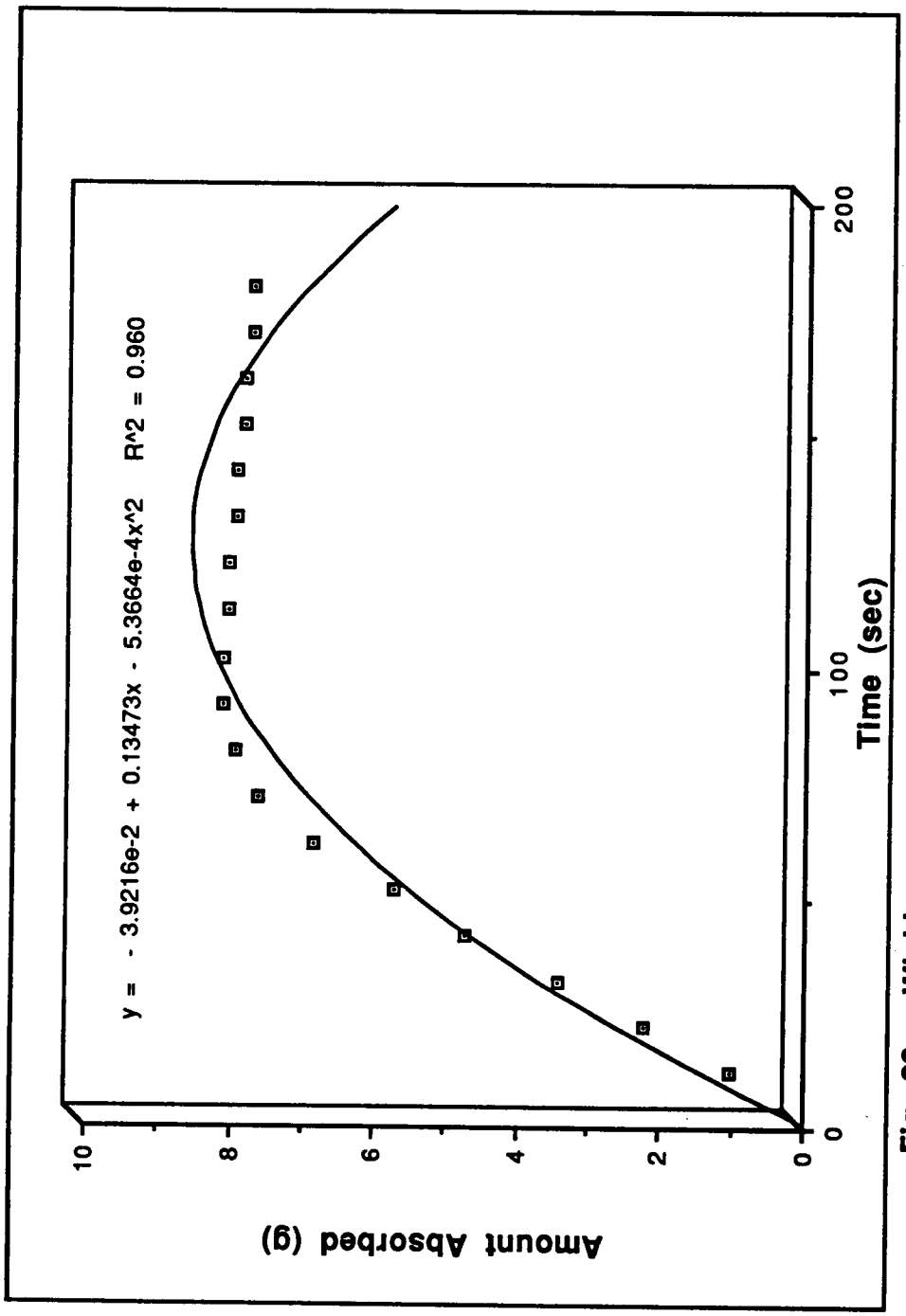


Fig. 28 – Wicking response curve for 1.0 oz/sq.yd cotton web without being laminated to melt blown or spunbond webs.

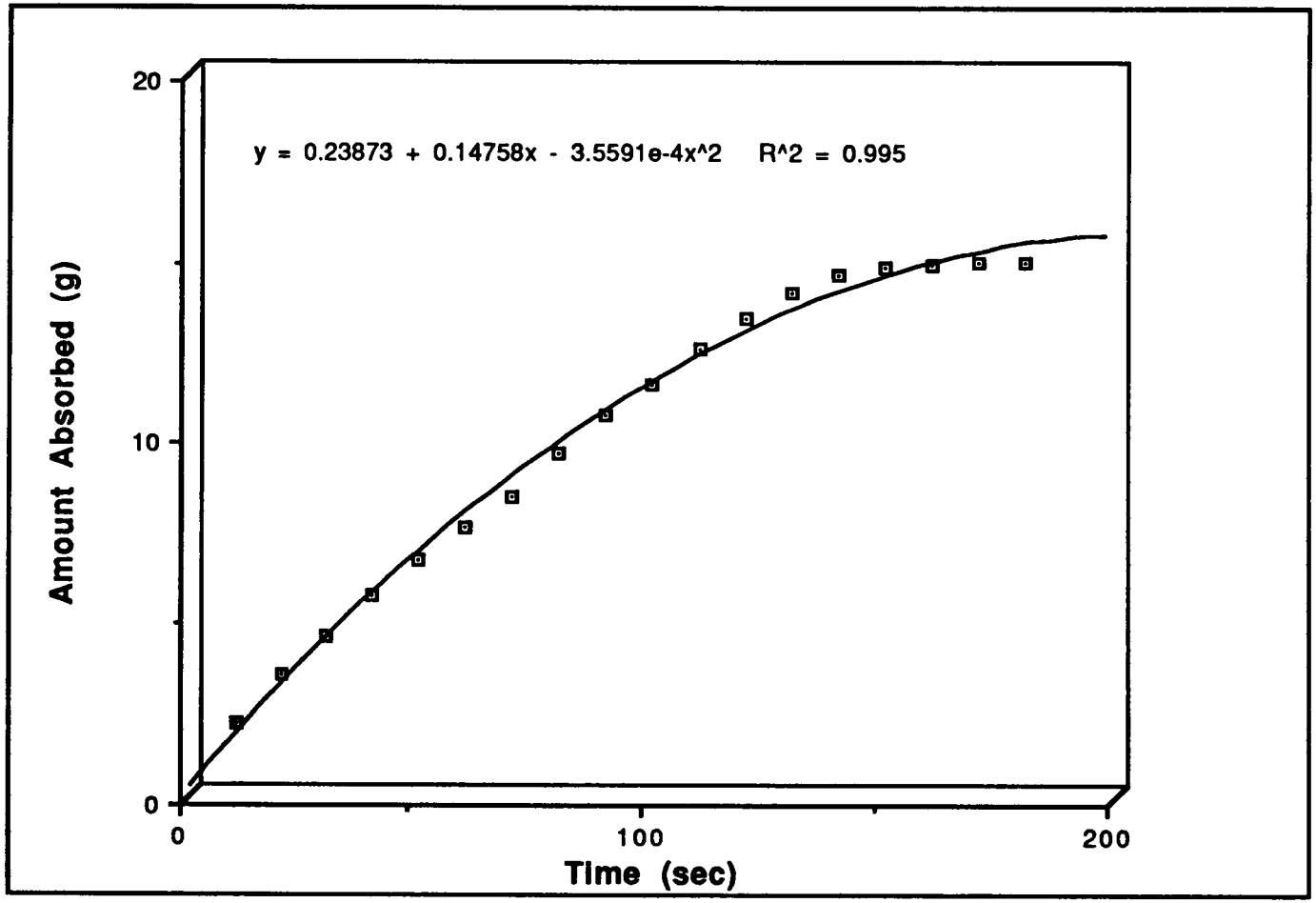


Fig. 29 -- Wicking response curve for 2.0 oz/sq.yd cotton web without being laminated to melt blown or spunbond webs.

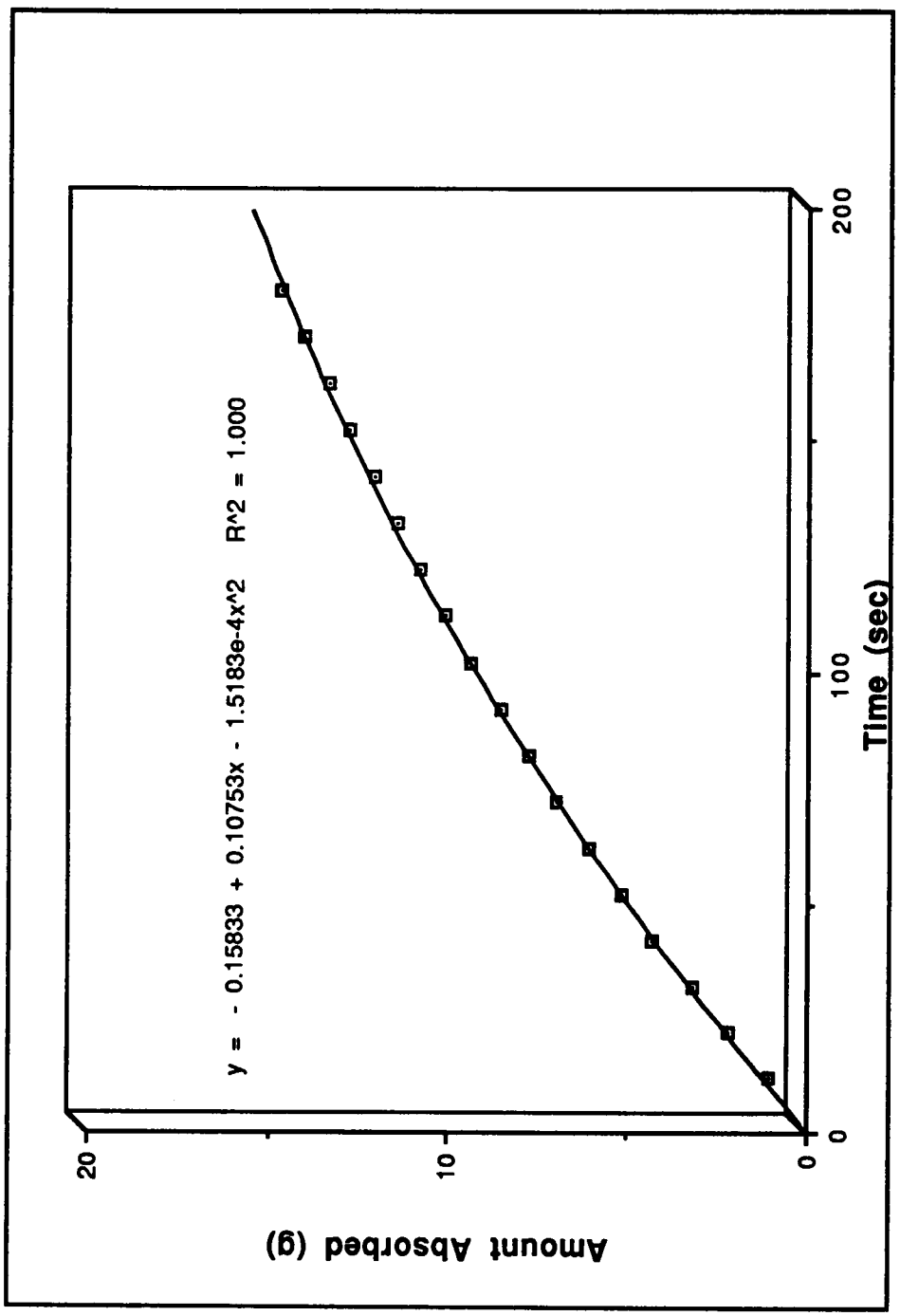


Fig. 30 -- Wicking response curve for 3.0 oz/sq.yd cotton web without being laminated to melt blown or spunbond webs.

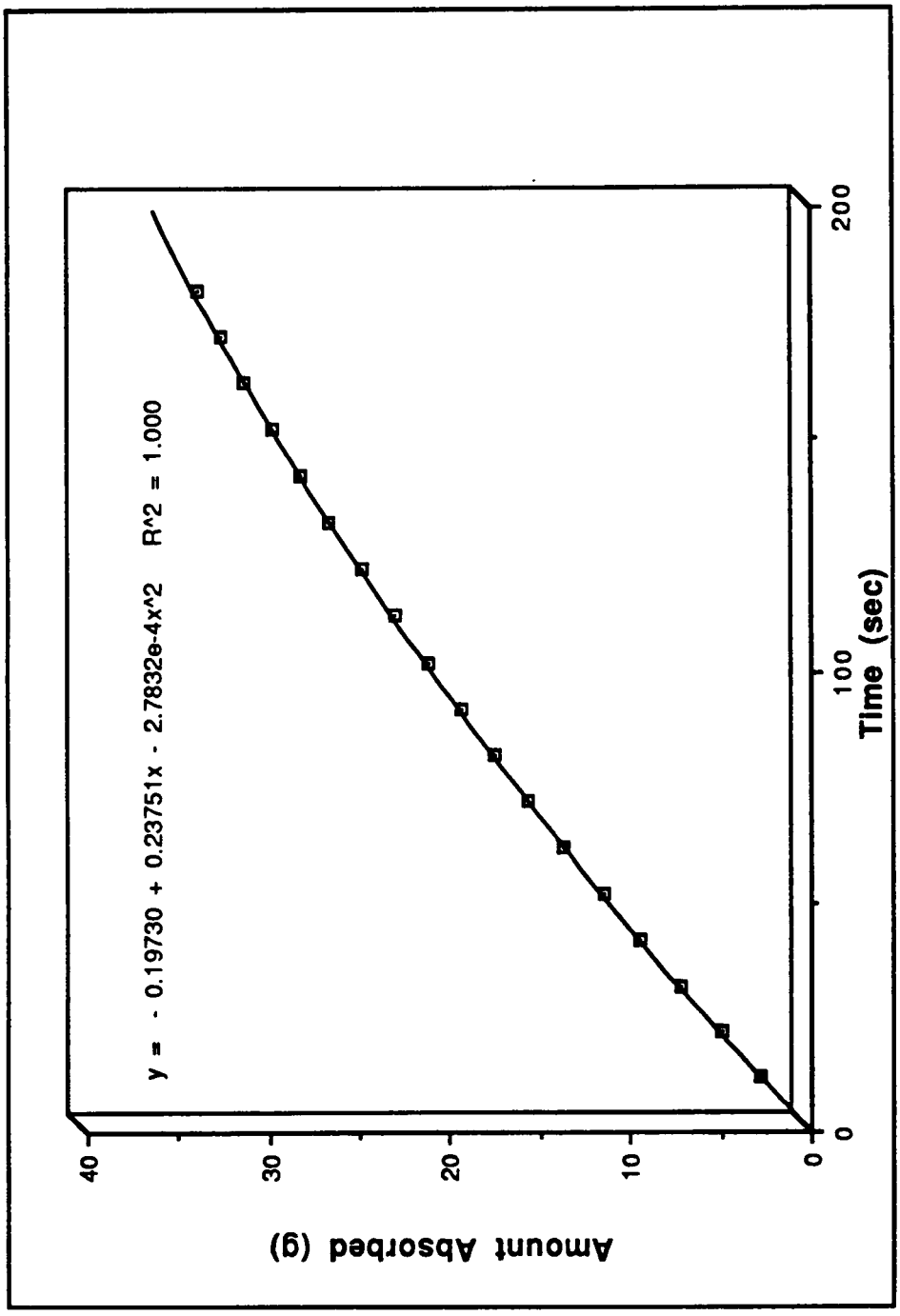


Fig. 31 -- Wicking response curve for 4.0 oz/sq.yd cotton web without being laminated to melt blown or spunbond webs.

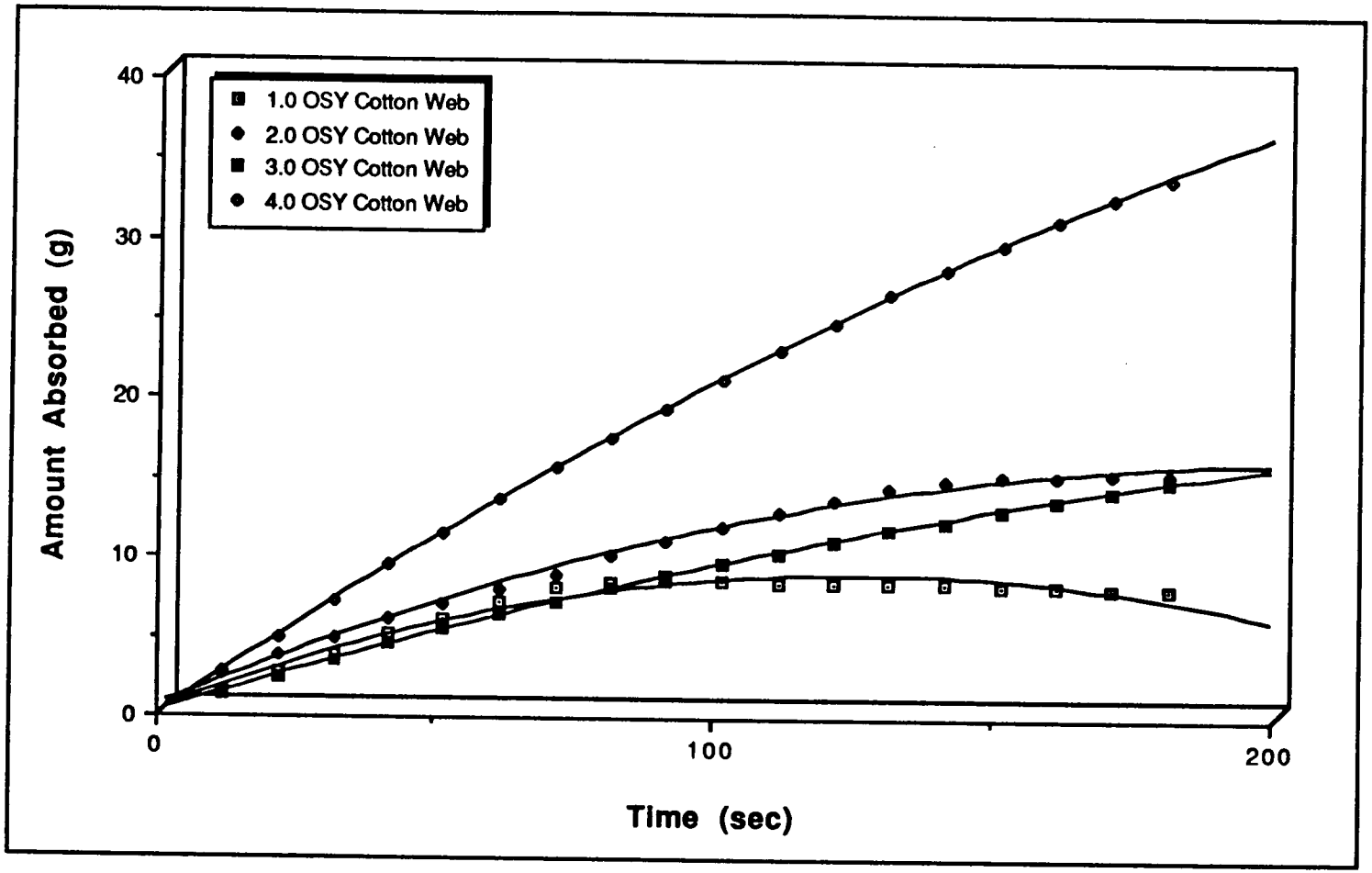


Fig. 32 -- Wicking response curves for 100% cotton webs of different weights without being laminated to melt blown or spunbond webs.

VITA

Nataraj Gosavi is from Karnataka, a southern state in India. He obtained his Bachelor of Technology (B. Tech) Degree in Textile Technology from the University of Mysore in December 1988. He joined the University of Tennessee, Knoxville in Spring 1990 and has since worked towards a M.S. degree.