INFECTION CONTROL AND BARRIER MATERIALS: AN OVERVIEW

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INTRODUCTION

With the increased awareness of infectious diseases such as Severe Acute Respiratory Syndrome (SARS) and 'Bird Flue', it is important that more attention should be focused on public hygiene. It is known that microorganisms such as bacteria, virus and fungi create and aggravate problems in hospitals and other environments by transmitting diseases and infections through clothing, bedding etc. Patients in hospitals are more prone to infection and the hospital acquired infections are among the top ten leading causes of death[1]. In spite of a great deal of research, clinicians are still facing problems with Methicillin resistant *Staphylococcus aureus* (MRSA) and Methicillin susceptible *Staphylococcus aureus* (MRSSA) bacteria in hospitals. When antibiotics are used incorrectly (for example, to treat colds and flu) and too frequently, bacteria will adapt and change to prevent being destroyed. Bacteria are antibiotic resistant when an antibiotic can no longer kill them. It may be noted that bacteria are usually active at pH 7.0-8.0 and fungi at 4.0-6.5. Fungal growth on textile materials is more rapid at RH greater than 80%[2]. Thus microorganisms exist in abundant quantities on textile materials and propagate diseases and infections and also cause damage to fibres under normal usage and storage conditions.

Infection control is a growing problem in places where hygiene is required and particularly in hospitals. Traditional muslin materials have been replaced by barrier materials in hospitals in the developed countries. Most of the clothing and garments used to protect cross infections from patient to patient and patient to medical personnel possess barrier properties that resist not only the entry of blood and liquids but also microorganisms. Such hospital garments, for example surgical gowns, gloves and drapes are not comfortable to wear for a long periods due to barrier properties. The performance of hospital textiles, thus, demands a balance between barrier and comfort properties. Initially cotton was mostly used in gowns and drapes and now polyester and polypropylene fibres dominate in most of hospital textiles. Rutala et al[3] and Patel et al[4] have reviewed the single use and reusable gowns and drapes in hospitals. The efficiency of the gowns in protecting cross infections has not been scientifically studied. However it has been found that higher barrier properties against microorganisms could be achieved in the surgical gowns that possess higher fabric repellency and smaller pore size[5]. Bacterial contamination in fabric stethoscope covers represents a potential infection control problem because they are used for prolonged periods and seldom laundered[6]. The Centres for Disease Control and Prevention (CDC), Atlanta, USA has established that there is limited clinical data to understand the relationship between the properties of gowns and drapes and Surgical Site Infections (SSI) risk[7].

INFECTION CONTROL BARRIER HOSPITAL TEXTILES

Hospital protective garments

Protective garments protect both patients and medical professionals from cross infection in the hospitals. Typically these garments are used as gowns, laboratory coats, coveralls,

headwear, footwear and facial protection. The gowns are designed either single layer or reinforced double and mlltilayer depending on the level of protection in hospital environments such as operating rooms, post operative blocks and bedding areas. A single layer gown could be a highly repellent fabric intented for use where minimal fluid is present. Reinforced and multilayer gowns are intended for use in the areas where high level of protection is required. A highly protective three layer gown consists of a tough outer layer that resists abrasion and puncture, a middle layer provides resistance to fluid penetration and inner is a soft layer which adds comfort in addition to protection. The pore size of the gowns is designed to prevent the penetration of microorganisms but allows gaseous exchange. Impervious gowns prevent strike-through during fluid intensive procedures. Drapes are designed to prevent hospital-acquired infections, and are for single or multiple uses. Single use and reusable gowns and drapes are usually made from cotton, polyester, polypropylene and their blends and are widely available in Europe. A good source of references for further reading can be found elsewhere[8-10].

Nonwoven medical products are being increasingly used in hospitals although disposability of single use products pose environmental concerns. Both spunlaced and spunlaid composites are used to produce surgical gowns and drapes. Spunlaced material provides enhanced comfort and aesthetic properties but spunlaid materials offer superior barrier properties. Spunbond-Melt blown-Spunbond (SMS) products possess the highest level of protection, and their softness and comfort have been improved considerably. A typical isolation and cover gown consists of a single layer spunbonded basic cover or a three-layer SMS fabric for increased barrier properties, softness and comfort. SMS fabrics are also used to produce laboratory coats, jackets and coveralls.

Testing of protective garments

According to the European Medical Devices Directive (93/42/EEC) of 13 June 1993, which came into effect on 1 January 1995, medical products including gowns and drapes must provide a high level of protection for patients, users and others. Surgical gowns, drapes and clean air suits are classified as medical devices as they are used for the prevention of diseases. All medical devices placed on the market must bear the CE certification mark. The Medicines and Healthcare Products Regulatory Agency (MHRA) of the UK views that surgical gowns and surgical drapes used in operating theatre are medical devices. However, other gowns and drapes not described as 'surgical' should not be CE marked as medical devices[11].

The CEN committee of European Standards Organisation (CEN/TC205/WG14) is developing European Standards for gowns, drapes and clean air suits[4]. The new directive is targeted to ensure high level of safety for users, patients and others. The directive consists of three parts in which part I (EN13795) was published in December 2002 and addressed the various performance characteristics required for surgical gowns, drapes and clean air suits to prevent transmission of infective agents between patients and clinicians during surgical procedures. Parts II and III are expected to be released in due course, and are expected to contain physical test methods and performance requirements respectively. In addition the EEC is funding a research programme named 'BIOBAR' with the aim to develop and validate test methods and classification systems for the assessment of barrier properties of materials against biological hazards, encountered in both occupational safety and in hospital situations. BIOBAR is not related to the CEN/TC 205/WG14 work, even though the results of their research will be highly relevant to that committee. At present the following standard test methods, in

addition to common strength tests (tensile, tear and bursting), comfort and absorbency, are normally carried out on hospital protective textiles.

Table 1. Industrial Test Methods for Hospital Protective Textiles

Test	Standard/Property
Hydrostatic pressure (Measures the resistance of fabrics to the penetration of water under constantly increasing hydrostatic pressure)	AATCC 127-1998; Test the performance of products under external pressure fluids present on the fabrics
Water impact (Measures the resistance of fabrics to the penetration of water by spray impact)	AATCC 22-2001; Test the performance of products when fluids fall or spray onto the fabrics
Mason jar (Measures the resistance of fabrics to the penetration of water under constant pressure)	IST 80.5-1995; Test the performance of products when fluids remain standing on one area of fabric
Alcohol repellency (Measures the resistance of fabrics to the penetration by aqueous isopropyl alcohol)	IST 80.6-1995; Test the performance of products when alcohol, blood and body fluids come in contact with the fabric
Microbial resistance (Measures the resistance of fabrics against microorganisms)	AATCC 147-1998 (Qualitative test) and AATCC 100-1999 (Quantitative test); to determine the degree of antibacterial activity AATCC 30-1999; To determine the susceptibility of materials to mildew and rot

Antimicrobial activity

With a view to develop antimicrobial textile materials, considerable research has been carried out by making use of organic and inorganic compounds, antibiotics, heterocyclics, quaternary ammonium compounds and so on. The biocidal properties of silver compounds have been known for thousands of years, and have been increasingly used nowadays to impart antibacterial properties to textile materials for hospital use[12]. Vigo et al[13-15] have carried out several studies ranging from fundamental aspects to development of antimicribial fabrics. Antibacterial polyester fabrics have been developed by imbuing antibacterial agents into the structure of fibres rather than depositing on their surface for longer durability and effect[16]. It is stated that the efficacy of the finished fabric to arrest the growth of *Staphylococcus aureus* and *Escherichia coli* is about 5 times higher than the conventional materials. A synergistic system of formulation comprising of inorganic chemicals involving a metal salt of a monocarboxylic acid, a carbamic acid derivative, a chealating agent, a boron compound, a dimethylene siloxane derivative and an alkane polymer has been proved to serve as an effective antimicrobial agent in arresting the growth of several bacteria (Gram positive and Gram negative), fungi and mildew[17, 18]. Hospital trials showed a dramatic decrease in bacteria, fungi and mildew growth in treated fabrics. The treatment also prevents the deterioration of fabrics by microorganisms. Chitosan treatment on cotton renders antimicrobial activity. Chitosan treated cotton fabric showed a high reduction rate in the number of colonies[19]. Fabrics made from viscose fibres containing polysilicic acid (Visil) and aluminium silicate (Visil AP) have been given urea peroxide treatment to

make them antibacterial as well as deodorant[20]. Instead of treating the surface of the fabrics with polymer coating, antibacterial additives have been imbedded into the fabric's polymer fibres for the production of antibacterial gowns[21]. Holme[22] has recently reviewed the current commercial antimicrobial finishes. A nonwoven composite barrier fabric comprising of a microporous thermoplastic film thermally bonded to layers of spunlaid nonwoven polyolefin has been made to resist the penetration by blood-born pathogenic organisms[23]. Besides the fabric possesses microporous structure that allows air and water vapour to pass through but not liquids, and is of immense benefit especially in operating theatre protective clothing and cover sheets. It must be stressed that the operating theatre fabrics should meet three primary requirements such as non-transmission of fluids and microorganisms, high absorbency and air and vapour permeability or breathability[24]. In addition to antibacterial materials, special bedding products that are impermeable to dust mites have also been developed[25].

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THE USE OF DYE-LIKE INTERACTIONS FOR DEVELOPING NOVEL INFECTION-RESISTANT MATERIALS

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ABSTRACT

Textile and other polymeric materials are ubiquitous in medical devices, whether used in implanted (e.g. prosthetic arterial grafts, prosthetic valve sewing cuffs), percutaneous (e.g. catheters, sutures) or extra-corporeal (e.g. wound dressings, cardiac bypass pump tubing) devices.

Depending on the use (in or out of the body, short or long term), these materials can suffer a variety of problems. One of the most significant is that of infection. Infection affects both the biomaterial and the patient. Infection in the biomaterial leads to failure, and the need for replacement with associated cost and risks. For the patient, limb loss and mortality are potential outcomes. The treatment for an infected biomaterial is typically a systemic dosage of antibiotic that represents a potential source of resistant strains of bacteria. For urinary and indwelling catheters the infection rate is as high as 40%. This series of projects began originally to look specifically at prosthetic arterial grafts, and problems of infection associated with them. It has led to a series of projects in which dye-like interactions of several different biomedical materials with bioactive materials have produced potentially useful products.

POLYESTER ARTERIAL GRAFTS

Prosthetic arterial grafts are typically either polytetrafluoroethylene (Goretex™) or knitted polyester (Dacron), range in diameter from 6mm to 13mm, and are used in lengths from 20mm to 900mm[1]. More than 250,000 are used each year in the US as a means of replacing a blocked or damaged artery when disease progression or previous use means a vein transplanted from elsewhere in the body is not available. Despite stringent operating room sterility, and antibiotics administered during the operation, between 2 and 6% of arterial grafts become infected, with roughly half of these infections resulting in death[2,3]. The failure rate of small and medium diameter grafts is even higher. The most common bacteria that cause problems are *Staphylococcus aureus* (*S. aureus*) and *Staphylococcus epidermidis* (*S. epidermidis*), with infections arising within a few days or weeks respectively.

Combating infection requires the use of one of the many available antibiotics, which vary in mode of action, spectrum of activity and side effects [4]. Many attempts to provide infection resistance beyond that available with surface application have been made, and these have been reviewed extensively elsewhere[5,6]. They tend to involve some kind of binding agent to hold the antibiotic in place for a time. Despite this extensive prior research, no commercially successful product has yet been developed with controlled and sustained release of antibiotic, preferably without the use of extraneous materials/binders that can interfere with the intended therapeutic effects.

Our initial efforts involved a variety of approaches[7]. Treated materials were tested for antibiotic activity via a zone of inhibition assay after applying them to an agar gel streaked with *S. aureus* and incubating the plates for 24 hours.

A series of commercial disperse and mordant dyes were applied to polyester and tested in substance to see if they possessed any antimicrobial activity. CI Mordant Red 11 (Alizarine) was mordanted (both before and after application to polyester) with silver. CI Disperse Blue 1 (with four amine groups) was applied as a source of 'anchors', to which antibiotics might be covalently linked. Turning to commercial antibiotics, we selected fluoroquinolones[8], because of their broad antimicrobial spectrum, heat stability, and, based on their limited water solubility and molecular size/shape, their similarity to disperse dyes. The two quinolone antibiotics utilized were Ciprofloxacin (Cipro®, Miles)[9] and Ofloxacin (Oflox®, Johnson and Johnson) (Fig.1). To render Cipro even more dye-like the carboxylic acid group was esterified and the silver salt prepared. None of these approaches demonstrated long term infection resistance.

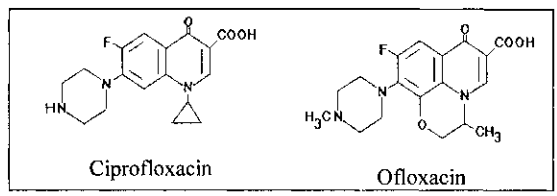

Figure 1. Structures of Cipro and Oflox

As is often the case, the simplest approach proved to be the best. The two fluoroquinolone antibiotics were used "as is" for application to polyester. Using a standard polyester exhaust dyeing method, 2% (owf) Cipro and Oflox were applied to polyester at a liquor ratio of 50:1, pH 4.5 and at 130°C for 1 hour. Neither Cipro nor Oflox exhausted to any significant extent, but the heat and hydrolytic stability of these two antibiotics were shown to be good. The next step was to apply the two antibiotics using a thermofixation procedure: $1cm^2$ polyester fabric pieces were dipped in 5g/l solutions of Cipro and Oflox. They were squeezed to a wet pick-up level of 65%, air dried and then heated at 210°C for 2 minutes. Materials treated similarly but without the heating step were used as "dipped" controls. Since these antibiotics are fluorescent, fibres from treated grafts were examined microscopically under UV illumination. Longitudinal views of fibres treated with Cipro by pad-heating showed fluorescence, but the corresponding cross-section showed this to be confined to the fibre surface. The amount of Cipro bound to fibre was calculated to be 33 ± 3.0 $\mu g/cm^2$ (n=12). The materials that demonstrated a persistent zone of inhibition were investigated further.

In order to simulate the continuous flow of bodily fluid past a treated biomaterial, a much more severe test of antimicrobial persistence than is usual in such studies was undertaken. Samples were continuously agitated in 5ml PBS at 37°C. Samples of solution were removed at various times, and the antibiotic concentration measured. After each sample was removed, the rinsing bath was replaced. A parallel experiment was used to test the zone of inhibition of the treated pieces after these same "wash" times. The pieces were autoclaved and embedded into agar plates streaked with *S. aureus*. Zones of inhibition after 24 hours incubation were measured.

Fig. 2 shows the release of Cipro and Oflox from dipped and pad-heat treated grafts. All of the Cipro is lost from the dipped sample after 48 hours, while the pad-heat

treated sample retained around 20% even after 96 hours with slow release persisting. The corresponding data for Oflox are similar, but there is no measurable long-term release.

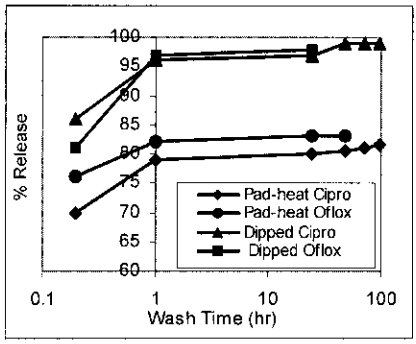

Figure 2. Release of Antibiotic from Dipped and Pad-heated Polyester

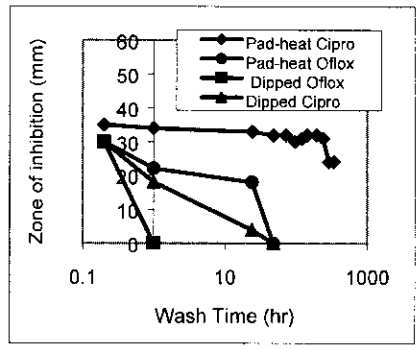

Figure 3. Zones of Inhibition of Dipped and Pad-heated Polyester

Figure 3 compares the zone of inhibition with time of grafts treated with Cipro and Oflox, dipped and pad-heated. Dipped samples exhibited a zone of inhibition for a short time after their washing commenced. Oflox pad-heat treated samples showed no zone of inhibition after 48 hours of washing, although the graft still exhibited fluorescence that indicated antibiotic still to be present. The antibiotic was firmly bound to the polyester and thus unavailable for antimicrobial activity. The Cipro pad-heat treated grafts showed inhibition zones for 336 hours (at which time all the samples were used up) indicating that 20% of antibiotic retained after application, and washing continued to leach slowly from the graft.

The results from these experiments were encouraging enough to conduct *in vivo* testing[10]. In a series of experiments samples of Cipro treated (pad-heated and dipped) and untreated polyester were inserted into pouches sterily cut into the rabbit dorsum and inoculated with 1 X 10^6 *S.aureus*. After 1 week, the samples were removed. The level of infection was assessed visually on a 1-4 scale (with 1 being the best). The graft samples were sonicated and the sonicate solution was backplated onto agar plates, incubated, and the number of colony forming units (cfu's) counted. The sonicated grafts were examined for remaining bacterial contamination by histology staining techniques. The results of the *in vivo* work, both in terms of the grading of the infection level, and the measure of culture positive grafts recovered from exposure corresponded largely with the *in vitro* results (Figure 4). Untreated grafts were the worst. Applying Cipro by dipping was an improvement, but the continued leaching of Cipro applied by pad-heat provided a much better graft.

POLYURETHANE

Polyurethanes are an important family of biomaterials with good tissue and blood compatibility, and they are frequently used for implantable devices, including heart valves, artificial organs, blood filters, catheters, wound dressings, pacemaker leads, and prosthetic grafts. Structural variation leads to materials ranging from rigid plastics to flexible foams, thus they are widely used today. As part of a study to examine the

covalent linking of bioactive proteins to medical materials, a polyurethane with carboxylic acid functional groups in the chain extender was made. As an aside, its dyeing properties were examined: initially with commercial dyes, and later with Cipro and Oflox in two series of experiments[11,12].

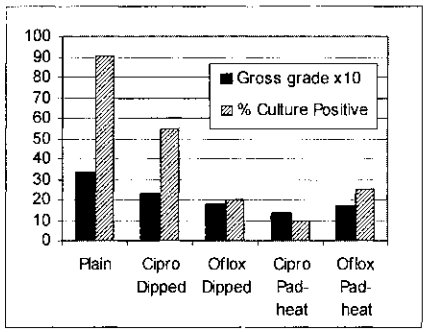

Figure 4. *In vivo* Testing of Polyester Graft Material

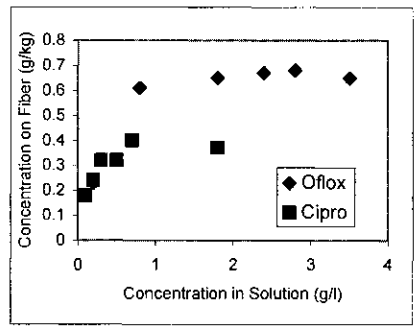

Figure 5. Dyeing Isotherms on Carboxylated Polyurethane

Initial studies showed that, unlike polyester, the carboxylated polyurethane was dyeable under "exhaust" conditions with Cipro. A range of dyeing conditions was examined in order to obtain maximum exhaustion of Cipro on this material, which was found to be at liquor ratio of 20:1, at pH of 8.6, and at temperature of 45°C. Based on the uptake of a range of Cipro concentrations under these conditions, and a time (3.5h) that suggests establishment of equilibrium, a range of Cipro concentrations was applied. The final concentrations of Cipro in solution and on the fibre for each dyeing were determined and a dyeing isotherm constructed. The result is shown in Fig. 5. An analysis of the plot indicated a Langmuir isotherm and implied a site mechanism for the dyeing, logical given the lack of uptake on the corresponding non-carboxylated polyurethane. This analysis also leads to the saturation value and partition coefficient K, and from the latter (with a number of assumptions) a value for the standard affinity was calculated. For a value of K = 5.90, the standard affinity, $-\Delta\mu^0 = 4.69$ kJ/mol. This value is of the same order of magnitude, but lower than the usual range of quoted values for standard affinities for a wide range of dye fibre systems[13].

A second study to examine the interaction of the polyurethane with Oflox used pH conditions extended to higher levels and somewhat surprisingly; uptake was considerably greater at elevated pH levels. This may be due to anionic repulsion between polyurethane chains allowing for greater penetration by the dyeing solution. The best conditions were found to be at 55°C for 3.5 hours at pH 11.5. As with Cipro, a range of concentrations was applied at a single temperature to build a dyeing isotherm. The isotherm is also shown as part of Fig. 4 (but note the two isotherms were obtained under slightly different conditions). The saturation value is higher as discussed earlier, and the value for the standard affinity, based on a K value of 2.2, is calculated to be 2.1 kJ/mol. This value is lower than that found for the same polyurethane dyed with Cipro.

To measure the release of antibiotic from these dyed polyurethanes, the same testing was used. Measurement of release showed the Oflox leaching rate is faster than that of Cipro, especially on the first day. The Cipro-dyed specimens had significant levels of

antibiotic release over 9 days followed by minimal release at 10 days. Oflox release was sustained for 4 days. This result correlated with the calculated values of affinity. Table 1 compares uptake and zones of inhibition of Cipro and Oflox. The dyeing conditions for Cipro and Oflox are close to the optimum found in the two studies. The data in the table indicate that Cipro-treated carboxylated polyurethanes have a longer time of sustained antimicrobial activity (10 days), despite a lower absolute uptake. In this case the lower affinity corresponds to a faster release. These results point to the possibility of predicting release persistence from standard dyeing data.

Table 1. Dye Uptake and Zones of Inhibition of Cipro and Oflox on Carboxylated Polyurethane

Dyeing conditions: LR=20:1, 3.5 hrs, 55 °C	Cipro (pH = 8.6, 2%owf)	Oflox (pH=11.5, 5%owf)
Uptake	15.0 g/kg	35.1 g/kg
Persistence of Zone of inhibition (wash time)	10 days	8 days

OTHER FIBRES

Given the interesting results from the application of antibiotics to polyurethane and polyester, this work has been extended to examine broader ranges of fibres and antibiotics and antifungal agents. In a series of studies funded by the US Army, Cipro and a range of other similar therapeutic agents have been applied to a series of textile fibres. Once again we have sought to establish the uptake of these agents and the corresponding *in vitro* release and efficacy exhibited by the treated fibres. The methods and results are discussed elsewhere[14]. To examine the effects of changes in fibre structure, we also looked at the effects of a pre-dyeing alkaline hydrolysis treatment on the uptake. Changes in fibre structure were assessed using FTIR spectroscopy.

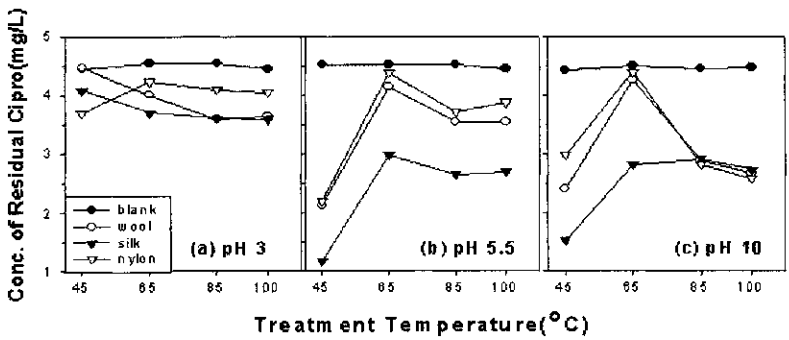

Figure 6.Uptake of Cipro on Silk, Wool and Nylon at Various pHs and Temperatures

Using Cipro as an example once more, when applied to silk, wool and nylon at pH 3 electronic repulsion resulted in a consistently low (ca. 20%) uptake on these fibres at all dyeing temperatures. The effect of pH was clearly seen at higher temperatures of application where there was greater sorption of Cipro at pH 5.5 and 10. At pH 5.5 and

10, wool and nylon showed very similar pH effects, and their apparent sorption of Cipro was the same. This indicated that nylon was as dyeable as wool by Cipro at higher temperature and pH. Visual observation of the Ciprodyed substrates under fluorescent light revealed that Cipro in wool was diffused into interior of fibres, whereas, the Cipro on nylon was apparently confined to the fibre surface. The disparity in location of antibiotics within the fibre would eventually result in different behaviour in antibiotic release during end-use. Dyeing conditions might be modified to produce deliberate variation in the location of antibiotic within the fibre.

Among the polyacrylonitrile (PAN) fibres, sorption of Cipro increased with an increase in temperature on Acrilan up to 85°C, but decreased again at 100°C. At pH 3 and at 100°C about 90% of Cipro was taken up by Orlon. The difference in sorption and exhaustion in two types of PAN was obviously due to their different comonomer compositions.

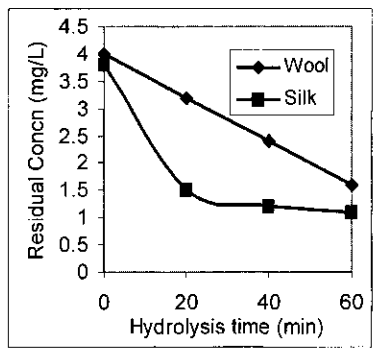

Figure 7. Effect of Hydrolysis on Cipro Uptake

Hydrolysis of silk drastically increased its Cipro sorption. High exhaustion can be obtained by hydrolysing silk for 20 min at 40°C with ca. 20% strength loss. Fig. 7 shows the uptake of Cipro on silk and wool at various times of hydrolysis. The FTIR spectrum and its second derivative confirmed scission of peptide bonds and conformational changes in silk fibroin occurred during hydrolysis reaction. Hydrolysis of silk caused considerable increase in zone of inhibition of Cipro-treated material. Hydrolysis treatment did produce silk with sustained release of Cipro.

Hydrolysis of wool also considerably increased the sorption of Cipro. Surprisingly, the effect of hydrolysis was more significant at low temperature dyeing, making the process more attractive to employ. Sorption of the antibiotic generally increased with increase in hydrolysis time, but the increase was the most substantial at first 20 min hydrolysis. At 45°C dyeing, wool hydrolysed for 60 min at 40°C showed 85.2% exhaustion of Cipro. FTIR analyses confirmed that a drastic increase in sorption of antibiotics by hydrolysed wool was due to increase in polar functional groups by peptide scission and in oxidised sulfur groups by cystine oxidation. Hydrolysis of nylon also drastically increased Cipro uptake, although sorption of Cipro was always lower in hydrolysed nylon than in hydrolysed wool. Among manufactured fibres, Orlon and Acrilan showed considerably improved sorption of both doxy and Cipro after hydrolysis, mostly due to increase in polar functional groups such as –COOH.

When these materials were analysed for their zones of inhibition we found that acrylic fibres had little or no antibiotic activity, indicating that the Cipro was locked within the structure. Nylon lost activity after 24 hours and the zone of inhibition of the Cipro-treated unhydrolysed silk decreased quickly with washing time and no activity remained beyond four hours. In both cases we suspected that the higher uptake corresponded with either a greater penetration within the fibre, or a high affinity holding the Cipro in place. If this is so, the Cipro will be still present within the fibre, and if used in a situation in which fibre biodegradation is possible (likely for silk), longer-term release is still possible.

On the other hand, substantial zones of inhibition were generally observed with the hydrolysed materials treated when dyed at 65°C and 85°C. Thus with careful control of hydrolysis and treatment conditions a highly infection-resistant silk with sustained release can be obtained by application of Cipro. These studies are in progress.

CONCLUSIONS

Using fluoroquinolone antibiotics as examples, we have shown that dye like interactions are possible on a wide range of textile fibres. Where no direct affinity exists, as on polyester, the "pad-heat" technique can still be used to imbue the material with sustained release and thus prolonged infection resistance. On polyurethane, low affinities allow for exhaustions less than 50%, but at the same time produce materials from which the antibiotic is also released in a sustained manner: there seems to be a correlation of affinity with duration of release. Extending the study to a wider range of textile fibres shows that by adjusting pH and temperature, and including a pre-hydrolysis, the uptake and release of Cipro can be varied widely. It also shows that in cases very good dyeing properties do not correlate with good antibiotic activity of the treated material.

Thus, this research is the first to successfully apply dyeing theory to create infection-resistant biomaterials.

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NYLON 6,6 KNITTED FABRICS WITH ANTIBACTERIAL PROPERTIES

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ABSTRACT

Graft copolymerisation of methacryloyloxyethyl trimethyl ammonium chloride monomer (METAC) on polyamide knitted fabrics using sodium persulfate as initiator was carried out. The content of METAC (quaternary ammonium groups) on polyamide fabrics is an important factor to affect their antibacterial activity.

The impact of graft modification on the surface fibers was evaluated by several techniques: thermal analysis, zeta potential measurements, elemental analysis and FTIR spectroscopy. The antibacterial activity of modified nylon 6,6 samples is studied against *S. aureus* by means of the antibacterial standard AFNOR, test method XP G39-100 and SEM observations.

INTRODUCTION

Some biocide families are known to act by contact with the cellular membrane such as quaternary ammonium salts[1,2]. In fact, quaternary ammonium group inhibits the growth of a wide variety of bacteria. The mechanism proposed for the antibacterial activity of the quaternary ammonium (QA) group is the polycationic nature of QA which interacts with the negative charges on the cell wall of bacteria[3,4,5]. When the grafted polyacrylamide fabrics charged positively, made contact with bacteria charged negatively, the quaternary ammonium cations on the grafted fabrics were released and adsorbed on the cell surface. This results in the diffusion of the cations through the cell wall and the destruction of the bacteria.

The scope of the current work was to graft a vinyl monomer bearing positive charges onto nylon fabric. This type of modification makes it possible to introduce biocide polymers into fibres that provide antibacterial properties[6,7,8,9]. The optimum conditions for graft copolymerisation were investigated.

To characterise the effect of graft modification on the surface fibres, the nylon 6,6 samples obtained were submitted to several analyses[10,11,12]. DSC allowed us to measure crystallinity of nylon 6,6 crystallites before and after grafting, thus, to localise grafted monomer chains. Besides, an elementary analysis was performed on the grafted fabrics at different grafting percentage to confirm the presence of METAC on the samples. The grafting onto nylon 6,6 was also confirmed through FTIR spectroscopy. Zeta potential increased from negative to positive with increasing grafting percentage (presence of quaternary ammonium charged positively).

Antibacterial activities of modified fabrics were examined by a viable cell counting method against *Staphylococcus aureus*. Treated textile is put in contact with a bacteria medium. The numbers of viable cells were calculated by counting the colonies.

EXPERIMENTAL

Materials

Nylon 6,6 monofilament fibres used throughout this work were kindly supplied by Nylstar. They were knitted. The vinyl monomer methacryloyloxyethyl trimethyl used was of pure grade and used without further treatments. The initiator employed in this study is sodium persulphate. Polyamide ammonium chloride knitted fabrics were used after soxhlet extraction in petroleum ether and dried at room temperature.

Grafting procedure

Polyamide knitted fabrics (0.5 g) were introduced into a three necked flask containing a required amount of the monomer and a definite volume of bi-distilled water. The solution was deaerated by passing pure nitrogen gas for 1 hour. The polymerisation was initiated by the addition of a known quantity of initiator. The flask was immediately placed in a thermostated oil bath. The time of adding the initiator was taken as the starting time for the reaction. The contents were stirred occasionally. The grafted knitted fabrics obtained were purified by extraction of untreated monomers and homopolymers with boiled water. After extraction, the grafted fabrics were dried in an oven for 24 hours[13].

Evidence of grafting

The grafting percentage was calculated by using the formula:

$$\% G = 100 \text{ (wt of grafted nylon- wt of nylon) / wt of nylon}$$

Fibre characterisation

Thermal analysis

The enthalpy of melting was measured by using a DSC-TA Instrument (2920). Experimentation was done from 25°C to 300°C under nitrogen atmosphere at a heating rate of 5°C/mn. The weight of sample was maintained at 6.5 mg.

FTIR spectroscopy

The FTIR spectrums were recorded for ungrafted and grafted nylon 6,6 using a microscope connected to FTIR spectrometer (Nicolet Nexus)[14].

Zeta potential measurement

To measure the electrokinetic properties of the modified fabrics, we used the Zetacad analyser from CAD-Instruments which is a specially designed automated equipment for the determination of zeta potential using the streaming potential technique[15,16]. The influence of the pH on the zeta potential was also investigated.

The streaming potential for polyamide fabrics was obtained at room temperature as a function of the applied pressure (0-500 mbar). The latter contains the fabric through which the electrolyte solution (KCl 10^{-3} M) is pumped. After the preparation of the

fabric measuring cell with approximately 0.5 g of fabric material, the cell was connected to the analyser and rinsed quickly with the KCl electrolyte solution followed by the removal of all the included air before the measurement started. Knowing the streaming potential and the pressure in the cell, the zeta potential 'ζ' is calculated by using this equation[17].

$$\xi = \frac{E}{\Delta P} \times 10000 \times 13.55 \times C \times \lambda$$

$(C = 16.32 - 0.35197 \times T + 0.00351 \times T^2)$

Where

ξ : zeta potential (mV) — ΔP : pressure (mBar)

E : tension (mV) — λ : conductivity ($S.cm^{-1}$)

Antibacterial assessment

Antibacterial activity was evaluated by examining the kill rate by the viable cell counting technique against *S. aureus*. 1 ml of bacterial suspension with a density of 10^6 cell/ml was spread on a Muller-Hinton agar[18]. The grafted nylon samples were cut into a disc of 3.8 mm diameter and put in contact with bacteria and then incubated at 37°C for 24 hours. After incubation, the samples were neutralised. 1 ml of the neutralised solution was added to 9 ml distilled water, several decimal dilutions were repeated. From this diluted solution, the surviving bacteria were counted. The test provides a quantitative evaluation of the residual bacterial activity of the sample.

RESULTS AND DISCUSSION

Graft copolymerisation

Percent grafting depends upon a large number of variables. Therefore, the effect of variables on percent grafting was investigated. During this study, one of the variables was varied and the other parameters were kept constant.

Variation of monomer and initiator concentrations

The effect of monomer concentration and initiator concentration on grafting percentage is presented in Fig. 1. The results show that grafting percentage increases when the monomer concentration increased up to 1.8 mol/l, then decreases. Varying initiator concentration acts as a monomer concentration. It is seen that increasing the sodium persulphate concentration up to 2.10^{-2} mol/l is accompanied by a significant enhancement in grafting percentage. At a higher concentration of monomer, the reactions that are competitive with the grafting probably take place in the solution like homopolymerisation. At higher initiator concentration, a redundancy of free radical is expected. As a result participation of the free radical in a termination process would be favoured over grafting, thus decreasing it.

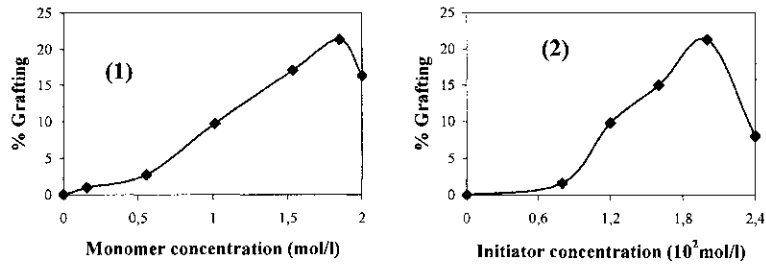

Figure 1. (1) Variation of the grafting percentage versus METAC concentration: initiator, $2*10^{-2}$mole/l; temperature, 90°C; time, 2 hours. (2) Variation of the grafting percentage versus initiator concentration: METAC, 1.8 mole/l; temperature, 90°C; time, 2 hours.

Variation of reaction temperature and reaction time

The results of graft copolymerisation under various conditions (temperature and time) are shown in Fig. 2.

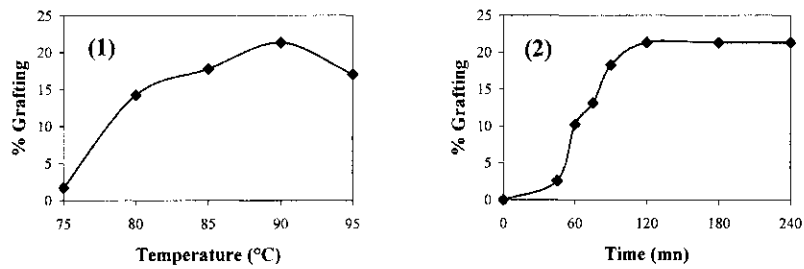

Figure 2. (1) Variation of the grafting percentage versus temperature reaction: METAC, 1.8 mole/l; initiator, 2×10^{-2}mole/l; time, 2 hours. (2) Variation of the grafting percentage versus time reaction: METAC, 1.8 mole/l; initiator, 2×10^{-2}mole/l; temperature, 90°C.

The graft copolymerisation was carried out at 5 different temperatures ranging from 75°C to 95°C keeping the other conditions constant. The increase may be related to the mobility of reactive species and the swellability of fibres.

It is observed that not only temperature but also time affects the grafting percentage. In fact, an increase up to 2 hours increases the grafting percentage.

Thermal analysis

The effect of graft polymers on morphological properties of polyamide was evaluated by Differential Scanning Calorimetry[19]. In order to compare the crystallinity in the PAM fibers, we used a crystallinity index, which is defined as the heat of fusion of the nylon 6,6 over the heat of fusion of 100 % crystalline nylon 6,6.

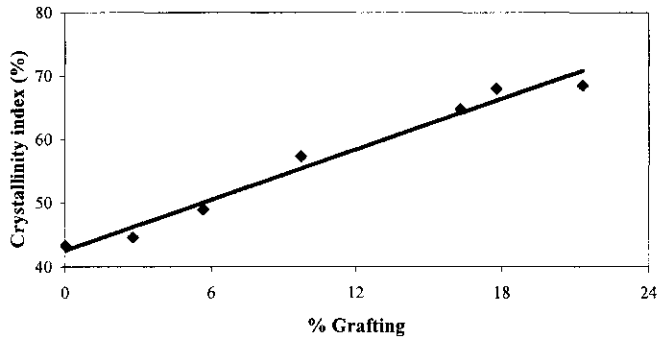

Figure 3. Variation of the percent crystallinity versus the grafting percentage

The DSC results obtained for ungrafted and grafted fibres are presented in Fig. 3. We observed an increase in PAM crystallinity with an increase in the grafting percentage. The increase in crystallinity is mainly due to the effect of the incorporation of the crystalline METAC that grafts in the fibre structure.

Elementary analysis

An elementary analysis was performed on grafted knitted fabrics in order to confirm the presence of graft and get the quantity of chlorine grafted on fibres. Results are presented in Table 1. The quantity of chlorine in grafted fabric increases since the grafting percentage increases to reach 6.58 % at a grafting percentage of 21.3%.

Table 1. Ratio of chlorine on nylon 6,6 fabrics at different grafting percentage

% Grafting	% Chloride
9.72	2.57
14.94	3.56
21.3	6.58

FTIR spectroscopy

The FTIR spectrum of ungrafted and grafted nylon 6,6 are given in Fig. 4. The peak of interest is 1730 cm^{-1} characteristic of the stretching vibration of -COOR group present in METAC polymer. This fact confirms the chemical grafting of METAC onto the nylon 6,6 fibres.

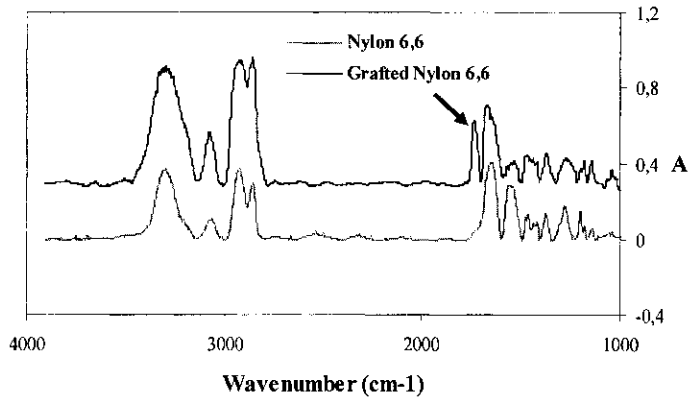

Figure 4. IR spectra of the original fabric and the grafted fabric

Zeta potential measurement

The streaming potential as a function of the pressure was recorded for untreated and treated fabrics at different grafting percentage keeping the pH value of the medium constant.

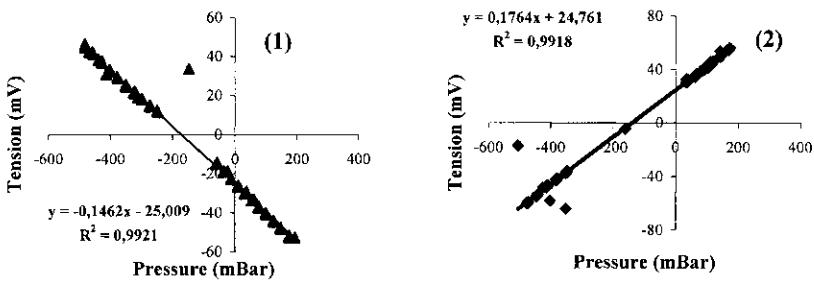

Figure 5. **(1)** Tension as a function of pressure for the original polyamide fabric;
(2) Tension as a function of pressure for the grafted fabric (% G = 17.41)

From the zeta potential values obtained for each fabric, information about the degree of interaction between the fabric and the ions of the electrolyte solution (KCl) was obtained. A negative zeta potential for untreated and a positive one for treated fabric (fig. 5) were observed.

Table 2 shows the relationship between zeta potential of PAM fabrics and grafting percentage. It is noticed the increase in zeta potential when the percentage grafting increases. Change of the sign of the zeta potential can be explained by the presence of quaternary ammonium groups (charged positively).

Table 2. Zeta potential as a function of grafting percentage

% Grafting	Zeta potential (mV)
0	-33
5.65	6.72
8.92	24.72
14.94	26.07
17.41	54.52

Antibacterial activity

The antibacterial activity of the grafted nylon 6,6 knitted fabrics against *S aureus*, a Gram-positive bacteria, was investigated. The results are presented in the Table 3.

Table 3. Evaluation of activity

	0 h		*24 h*	
	Cell count ml^{-1}	*Log*	*Cell count ml*$^{-1}$	*Log*
Batch N°1	$3.4*10^3$	3.53	$4.6*10^3$	3.66
Batch N°2	$2.4*10^3$	3.38	$2.4*10^3$	3.38
Batch N°3	$1.5*10^3$	3.17	$1.8*10^3$	3.25

From the first batch of the tests and after inoculation with the bacteria for 24 hours, only one sample among the batch shows a reduction of bacteria. That's why; two other batches have been tested. We notice no reduction of bacteria in all tested samples but no proliferation of bacteria. Although the monomer was effective in literature[8], he shows no efficacity by grafting it on nylon fabrics.

CONCLUSIONS

The grafting of nylon 6,6 fabrics with methacryloyloxyethyl trimethyl ammonium chloride monomer (METAC) using sodium persulphate has been studied. An ideal condition (1.8 mol/l monomer concentration, 2×10^{-2} mol/l initiator concentration, 90°C and 2 hours reaction time) has been optimized for a high degree of METAC grafting. Besides, the grafted fabrics possessed positive charges required for antibacterial activity. With the use of infrared spectroscopy, thermal and elementary analyses, it is reaffirmed the presence of METAC into the PAM fabrics. The zeta potential measurements, also revealed the presence of positive charges on PAM fabrics caused by grafting. Furthermore, antibacterial activities of grafted nylon knitted fabric against S. aureus have been evaluated by a viable cell counting method. The grafted knitted fabrics, having positive charges, exhibited no proliferation of bacteria.

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THE IMPACT OF AGEING ON THE PROPERTIES OF SINGLE-USE OR GARMENTS

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ABSTRACT

According to the ISO 11137 - Sterilisation of healthcare products - "Requirements for validation and routine control - Radiation sterilisation" and the United States Food and Drug Administration regulations, medical devices must be given an expiry date, which indicates how long they may be stored prior to use.

Real time ageing is the best way to do this, but no organisation can afford to delay its products launch waiting for the real time ageing tests.

A method of accelerated ageing is required that realistically recreates what a product may experience during storage.

Accelerated ageing is achieved by storing the product at an elevated temperature. The experimental conditions using ISO 11137 was testing the effect that ionising radiation (gamma and electron beam) would have on the stability of the materials that make up the materials of the operation room garment before and after ageing.

Testing included specific properties essential to the intended function of the product and the dose level was 25 kGy, the radiation doses usually used for this kind of product.

Since most of the medical devices can be stored until 5 years prior to use, after an inquiry including all national and private hospitals in Portugal and another survey in France, we discovered that the single-use products, also the operation room garments - aim of our research and considered a non-active medical device - is stored no longer than one year. So we simulated one-year storage and we will present the results in this paper.

Ageing trial

Accelerated ageing is achieved by storing the product at an elevated temperature. Clearly, there is a limit to the temperature that can be applied to a medical product or package that is made of plastic. Accelerated ageing must be carried out below the glass transition temperature of any components of the product. It is generally accepted that 60 °C is the maximum temperature that is suitable for most products (ASTM F1980) and the most indicated equipment is a climatic chamber.

Purpose and importance of sterilisation

The primary purpose of sterilising an item is to render it safe for use by destroying all living microscope organisms (EN 556).

Four common types of sterilisation are in use today: gas, irradiation, steam autoclave and dry heat. The two first types of sterilisation are also called low temperature sterilisation methods, applied to single-use products and the last to second types, high temperature sterilisation methods, applied to reusable products.

Gamma and electron beam irradiation

Radiation sterilisation can be accomplished using one of two forms of ionising radiation: gamma (electromagnetic radiation) and electron beam (particle radiation). Since repeated irradiation is equivalent to on going ageing treatments, irradiation techniques have been successful for single-use articles where only one dose is required. Polymers can also be modified, using irradiation, to improve physical properties and performance. However not all polymers will benefit and in fact many will degrade.

EXPERIMENTAL DETAILS

For gamma and electron beam irradiation, according to the European Standard EN 552 "Sterilization of medical devices - Validation and routine control of sterilization by irradiation", the minimum dose is 25 kGy. The products were processed in industrial irradiation process with validated parameters for a sterilisation process established for these medical devices - a real case study.

The operation room garment is the nonwoven (45% polyester, 55% cellulose) that has been irradiated. The nonwoven is a hydroentangled fabric, consolidated by the action of water jets.

The operation room garment reinforced materials that reinforce the barrier function are the nonwoven (45% polyester, 55% cellulose), a laminate (1st layer: 20g LDPE film; 2nd layer: nonwoven (70% viscose, 30% polyester) and a polyethylene film. The whole garment fabric then irradiated.

These materials reforce the barrier properties; however there is a perception in some medical staff minds about reducing the comfort.

The experimental conditions for the ageing trial according to ISO 11137 was testing the effect that radiation would have on the stability of the materials that make up the materials of the operation room garment.

Seven days at 60°C may be considered as equivalent to 180 days of ageing at ambient conditions.

We simulate one year so that the materials rest in the climatic chamber during 14 days. A climatic chamber, ARALAB was used in this study.

Operation room garments

Operation room garments are used by a surgical team to prevent transfer of cross-infection in the operating theatre.

According to the Medical Device Directive 93/42/EEC, operation room garments, drapes and air suits are considered to be medical devices whether they are reusable or single-use gowns and drapes.

The European Standard prEN 13795 - Surgical drapes, gowns and clean air suits used as medical devices for patients clinical staff and equipment define operation room garment as the product used in the operating theatre to prevent transfer of infective agents.

Operation room garments can be simple or reinforced (Fig 1). In the case of operation room gowns it is advisable to use the reinforced gowns. The gowns must be reinforced at the thoracic and abdominal regions and also the forearms must be reinforced.

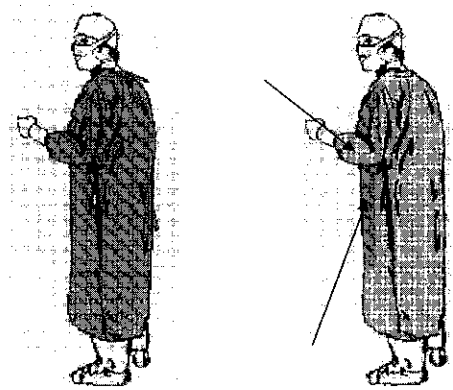

Figure 1. Simple and reinforced gown

These parts of the gown are considered as the critical zones with the major possibility to contact with blood and other saline solutions present during an operation. The gown must prevent the contact of these solutions with the medical and nurse staff, but also protect the patient from contamination.

In our research the gowns are single-use and the basic material, common for all gowns, is the repellent finished spunlaced nonwoven with an in and outer layer to reinforce the barrier function (Table 1).

Table 1. Tested gown material

Identification	Gown Material	
	Outer Layer	Inner Layer
A	Nonwoven	Nonwoven
B	PE	Nonwoven
C	Nonwoven	Laminate

Properties

Improving a fabric's capability to resist penetration can only be achieved by proportionately decreasing its permeability, making it less comfortable to wear. Increasing permeability, on the other hand, diminishes a fabric's ability to resist penetration. The only reasonable solution is a compromise between liquid resistance and air permeability for the sake of comfort.

Many objectively measured properties can be related to comfort. The objective factors considered in the assessment of comfort are usually the thermal properties, moisture properties, and fabric and fibre characteristics.

The study was carried out on the following properties: air permeability, liquid repellency and the thermal properties (heat absorption and thermal conductivity) of the materials presented in Table 1, which compose the gowns.

Table 2 shows the applied test methods, references and units to ascertain the properties studied.

Table 2. Properties, test methods, references and units

Property	Test Method	Reference	Units
Heat Absorption	Warm/Cool feeling (q_{max})	KES Specifications	W/m^2
Thermal Conductivity	Heat flow loss	KES Specifications	W/m°K
Liquid Repellency	Wet Barrier - Hydrostatic Head	ERT 160.0-89 (EN 20811)	mbar/min
Breathability	Air Permeability	ERT 140.2-99	$l/m^2/s$

RESULTS AND DISCUSSION

We have treated and compared the results before and after ageing with the different irradiation methods at a dose level of 25 kGy, to finally indicate the effect of the ageing over the studied materials and properties.

The results were also analysed using statistical methods before and after irradiation, to finally indicate the effect of these sterilisation methods over the studied materials and related properties, (Table 4-9) using the test of the variance (F-Snedecor Fisher), the test of the means (t-Student Fisher) and the analysis of variance.

The Table 4-9 show the effect of both ionising radiation ageing over the properties in study for each material involved, taking non-irradiated material as reference and indicating if it is statistically significant.

Heat absorption

For this property we considered both sides of the tested materials (face up and face down).

It can be seen that in the case of nonwoven (Table 4), compared with the value of non irradiated material:

- the face up values are higher than the face down values (in contact with the skin);
- the non-irradiated nonwoven, after ageing, decreases the heat absorption independently of the side obtaining the lowest value face down; and
- the electron beam and gamma radiation decrease the heat absorption face down, increase the face up, and for the electron beam radiation it is statistically non significant.

In the case of laminate compared with the value of non-irradiated material (Table 5):

- all values, regardless the radiation process, decrease.

In the case of the polyethylene compared with the value of non-irradiated material (Table 6):

- the non-irradiated nonwoven, after ageing, increases face up and decreases the heat absorption face down, but is statistically non-significant;
- the electron beam radiation increases for both sides; and
- the gamma radiation has the same behaviour as the electron beam radiation, but the values are higher for the gamma radiation.

Thermal conductivity

The thermal conductivity of nonwoven, laminate and polyethylene (Tables 4-6), compared with the value of non-irradiated material regardless the radiation process, increase after ageing.

Liquid Repellency

In the case of nonwoven (Table 7) compared with the value of non-irradiated material:
- all values, regardless the radiation process, increase after ageing but they were not statistically significant. Only in the case of the non-irradiated material after ageing are statistically significant.

In the case of laminate compared with the value of non-irradiated material (Table 8):
- the values increase after gamma radiation and decrease after electron beam radiation, being statistically significant for both cases. In the case of non-irradiated material after ageing the value increases, but isn't statistically significant.

In the case of polyethylene compared with the value of non-irradiated material (Table 9) all values, regardless the radiation process, decrease after ageing.

Air Permeability

For this property we considered both sides of the tested materials (face up and face down).

It is observed that in the case of nonwoven (Table 7) compared with the value of non- irradiated material:
- all values, regardless the radiation process, increase after ageing except for the electron beam radiation face up, but is not statistically significant.

In the case of laminate compared with the value of non-irradiated material (Table 8):
- all values, regardless the radiation process, increase after ageing face down, but face up maintains impermeable.

In the case of polyethylene (Table 9) the material is impermeable, independently of the side, radiation process and ageing, maintaining the original value of the property.

Table 3. Suitable irradiation method for each gown considered ageing

Gown/ Property	Heat Absorption		Thermal Conductivity		Air Permeability		Liquid Repellency	
A	Gamma Electron beam	↘	Gamma Electron beam	↗	Gamma	↗	Gamma Electron beam	↗
B	Gamma Electron beam	=	Gamma Electron beam	↗	Gamma	=	Electron beam	=
C	Gamma Electron beam	↘	Gamma Electron beam	↗	Gamma	↗	Electron beam	↗

Table 4. Statistical results for the nonwoven

Material		Nonwoven		
		Thermal Conductivity (W/m°K) FUP	Heat Absorption-Qmax (W/m²) FUP	FDOWN
Non-irradiated	Average	0.0334	12.0	9.3
	Average	0.0375	10.6	7.6
Non-irradiated after ageing		S	S	S
	Average	0.0392	12.2	9.0
Gamma radiation 25 kGy after ageing		S	S	S
	Average	0.0397	12.9	9.2
Electron Beam Radiation 25 kGy after ageing		S	NS	S

Table 5. Statistical results for the laminate

Material		Laminate		
		Thermal Conductivity (W/m°K) FUP	Heat Absorption-Qmax (W/m²) FUP	FDOWN
Non-irradiated	Average	0.0257	14.1	10.6
	Average	0.0311	10.9	7.5
Non-irradiated after ageing		S	S	S
	Average	0.0321	13.0	9.2
Gamma Radiation 25 kGy after ageing		S	S	S
	Average	0.0339	13.5	9.2
Electron Beam Radiation 25 kGy after ageing		S	S	S

Table 6. Statistical results for the polyethylene

Material		Polyethylene		
		Thermal Conductivity (W/m°K) FUP	Heat Absorption-Qmax (W/m²) FUP	FDOWN
Non-irradiated	Average	0.0255	12.3	13.6
	Average	0.0289	12.4	13.3
Non-irradiated after ageing		S	NS	NS
	Average	0.0288	15.4	15.9
Gamma Radiation 25 kGy after ageing		S	S	S

	Average	0.0296	15.0	15.5
Electron Beam Radiation 25 kGy after ageing		**S**	**S**	**S**

Table 7. Statistical results for the nonwoven

Material		**Nonwoven**		
		Liquid Repellency (mbar/min)	**Air Permeability ($l/m^2/s$)**	
		FUP	**FUP**	**FDOWN**
Non-irradiated	**Average**	24.5	295	292
	Average	26.6	318	323
Non-irradiated after ageing		**S**	**S**	**S**
	Average	26.4	298	295
Gamma Radiation 25 kGy after ageing		**NS**	**S**	**S**
	Average	25.7	289	295
Electron Beam Radiation 25 kGy after ageing		**NS**	**NS**	**S**

Table 8. Statistical results for the laminate

		Laminate		
		Liquid Repellency (mbar/min)	**Air Permeability ($l/m^2/s$)**	
		FUP	**FUP**	**FDOWN**
Non-irradiated	**Average**	99.2	0	0.166
	Average	106.6	0	0.250
Non-irradiated after ageing		**NS**	-	**S**
	Average	109.2	0	0.258
Gamma Radiation 25 kGy after ageing		**S**	-	**S**
	Average	84.2	0	0.235
Electron Beam Radiation 25 kGy after ageing		**S**	-	**S**

Table 9. Statistical results for the polyethylene

Material		**Polyethylene**		
		Liquid Repellency (mbar/min)	**Air Permeability ($l/m^2/s$)**	
		FUP	**FUP**	**FDOWN**
Non-irradiated	**Average**	296	0	0
	Average	277.8	0	0
Non-irradiated after ageing		**S**	-	-

	Average	278.0	0	0
Gamma Radiation 25 kGy after ageing		S	-	-
	Average	293.4	0	0
Electron Beam Radiation 25 kGy after ageing		S	-	-

Legend for Table 4-9: S - Significant; NS – Non Significant
FUP-Face up; FDOWN-Face down

CONCLUSIONS

The heat absorption, q_{max} (W/m^2), for the gown type A decreases after ageing except face up for the gamma radiation.

The gown type B maintains the heat absorption for the non-irradiated materials after ageing and for the different irradiations methods increase, because of the polyethylene.

The gown type C decreases the heat absorption after ageing and irradiation methods except for the gamma radiation face up where the heat absorption increases.

The heat absorption after the contact between the skin and the gown is generally low and, therefore, by wearing the gown the sensation of coolness is minimum, permitting a good sensation by touching the skin.

The ageing process doesn't influence the heat transfer properties since they improve undeniably for the different irradiation doses increasing the sensation of comfort.

The thermal conductivity ($W/m°K$) increases for all gown types after ageing, suggesting that the electron beam radiation is more efficient than the gamma radiation, because the values obtained are higher, consequently increasing the sensation of comfort for the thermal conductivity.

After the ageing process it is seen that the materials of the gowns A and C are more permeable for air and liquids, except for the electron beam radiation, regarding the liquid repellency property.

Regarding the gown B, the liquid repellency of the polyethylene doesn't permit a good sensation of comfort.

The available data suggest that all the materials maintain their stability in the range of dose values usually applied to medical devices sterilisation (15 to 40 kGy) before and after ageing.

Table 3 indicates the behaviour of material that composes the gown after ageing and the most suitable irradiation method.

Due to the composition of gown B, it is less influenced by ageing. Gowns A and C have the same behaviour, decreasing the heat absorption and increasing of the thermal conductivity, liquid repellency and air permeability.

The impact of gamma radiation is more significant than the electron beam radiation, but the product behaviour modifications exist in a small range.

The study underlines the necessity to find a compromise between the air permeability and liquid repellency for the sake of comfort and maximum protection.

ACKNOWLEDGEMENT

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THE USE OF AMICOR PURE TECHNOLOGY IN MEDICAL TEXTILES

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ABSTRACT

The Amicor Pure technology from Acordis provides a viable way forward in reducing the risk of cross contamination from textiles to patients in healthcare enduses. For a textile to offer this benefit it needs to be shown to be effective against relevant bacteria in real life situations and needs to maintain this performance through out the lifetime of the article. This paper gives details of the work carried out by Acordis to demonstrate that hospital textiles containing Amicor Pure are effective and durable. It also outlines the health benefits of Amicor bedding to people who are allergic to the allergen DerP1.

INTRODUCTION

Hospital acquired infections within the UK are estimated to result in 5000 deaths per year. Official figures suggest that around 100,000 patients acquire infections during their hospital stay with an associated cost of 1.4 billion Euro/year[1]. The underlying reasons for these frightening statistics are complex but some of the key factors are thought to be:

1. Reduction in environmental monitoring.
2. The emergence of antibiotic resistant bacteria.
3. Increased numbers of vulnerable patients.
4. Poorly defined national standards.

There are therefore a number of concerted efforts underway, to find ways of reducing these Hospital Acquired Infections. Two programmes, that I have a working knowledge of, are being co-ordinated through the Cornwall NHS Trust (in collaboration with the Hatherly Laboratories at Exeter University) and through Queens Medical in Belfast. These programmes are very wide reaching and are aimed at providing a package of measures that will help to minimise spread of these infections through the NHS. This in turn will minimise the risk of patients acquiring infections during their hospital stay.

One of the vehicles by which these infections can be transmitted around healthcare institutions and by which transfer from carer to patient or vice versa can be achieved are the people and the textiles that people wear within the healthcare institutions[2]. By people I mean nursing staff, doctors, ancillary workers and the patients.
Amicor Pure technology has the ability to protect hospital textiles from the development of a significant number of bacteria and fungi in between laundry cycles and we are therefore talking too and working with the NHS to demonstrate that Amicor textiles can reduce this risk of cross- infection.

The objectives of this presentation are therefore:

i) To give a profile of the company that I represent - Acordis.
ii) To provide some brief details of the problem of HAI's
iii) To describe to you how the Amicor Technology works and how it is made.
iv) To give some details of the extensive trials that we have done to demonstrate the effectiveness of textiles made using the Amicor technology.
v) To overview the benefits and enduses into which the Amicor technology is used.

ACORDIS

The Acordis group was formed in 1999 from the fibre businesses of two very respected companies with long histories in Textiles- Akzo Nobel and Courtaulds. The group is financed by the venture capital bank CVC with significant holdings from Akzo Nobel and Senior managers. Acordis is therefore a multinational group of companies supplying customers throughout the world with manmade fibres and speciality materials for industrial, textile, medical and hygiene applications. We had sales of 2.2 billion Euro in the year ending 2000, we employ 16000 people in production sites in Germany, Netherlands, UK, USA, Brazil , Italy, Spain and Poland.
The Amicor business is part of the Acrylics Division based in Bradford with a manufacturing plant in Grimsby.

HOSPITAL ACQUIRED INFECTIONS

I think that it is fair to say that in recent months hardly a week goes by without there being a news article concerning *Methicillin-resistant Staphylococcus aureus* (MRSA) infections within hospitals. The figures quoted at the beginning of this talk came from the National Audit office. The same source of information also reveals that in 1991 they recorded around 5000 cases of *Staphylococcus Aureus* infections acquired during a hospital stay and that 2% of these cases were of the MRSA resistant variant. In 2001 the number of reported cases had increased to over 13000 with 42% of them being the MRSA variant. If we go back to 1970 there were no acknowledged problems with MRSA, VRE *(Vancomycin-resistant Enterococcus)* or with multi-drug resistant Gram negatives. Clearly, this is a very frightening trend that needs to be stemmed. However, to put these figures into some perspective, it is important to understand that the patient population has also significantly changed. In 1970 there were very few transplant patients, leukemics or patients with indwelling devices. These are very vulnerable patients that make up a significant percentage of those acquiring these resistant bacterial infections.

The scope of the work within the Cornwall NHS Trust and at the Queens Medical in Belfast are therefore to test the efficacy of existing cleaning regimes, to acquire and test new materials and equipment for pathogen colonisation and decontamination. To design effective regimes going forward and to influence policy-making to provide and validate these new regimes[3]. Acordis believe that the Amicor technology provides a new material that is capable of making a significant contribution to these new regimes. We are therefore working with providers of hospital textiles (E.g.: Meltemi Company Clothing Ltd) to provide these improved textile articles. The Royal College of Nursing ran a fringe event at the recent RCN conference in Harrogate that addressed the concerns that nurses have with the current supply of uniforms and the laundering regimes currently being used. As part of these discussions it was acknowledged that hospital textiles do carry significant levels of bacteria within them and that very often, laundering procedures do not remove this risk[4,5].

Amicor Technology

Amicor is an acrylic based fibre into which is incorporated organic antibacterial and antifungal additives. Both additives are fully compliant with all legislative bodies. E.g.

EPA/FDA in the USA, the Biocidals directive in Europe and is listed on the OKOTEX white list of safe antimicrobials.

Amicor fibres are used in blends with any other fibre type at blend levels of between 10% and 30%. The resulting blends will be protected from the development of a wide range of bacteria and fungi for the lifetime of the product. The resulting blends can be dyed and finished, and are fully durable to washing. We have for example demonstrated the efficacy of Amicor/cotton sheets through 200 hospital laundry washes at 100°C. The technology can be applied to most textile end-uses, spun and nonwoven.

We currently use three sub brands for Amicor depending upon the end-uses into which they are used:

Amicor products will minimise the development of a wide range of bacteria within the textile article. Examples of bacteria controlled are: MRSA, *Staphylococcus aureus, Klebsiella pneumoniae, E.coli, Salmonella enteridis and Legionella pneumoniae.*

Amicor plus products will minimise the development of a wide range of bacteria and certain fungi within the textile. Examples of fungi controlled are *Trycophyton mentagrophytes and Aspergillus repens.*

Amicor Pure products will, as a result of the control of bacteria and fungi within the textile, minimise the development of bedmites and the allergen Derp1. Control of both of these provides benefits to asthmatics and eczema sufferers.

Amicor Pure fibres are made using a "Late Injection technology" in which functional additives are added to the polymer prior to fibre spinning. The resulting fibres contain a reservoir of finely dispersed additives, which in combination with the unique fibre morphology formed during the wet spinning of the fibre create a concentration gradient within the fibre. This facilitates the slow diffusion of these organic antimicrobial additives to the fibre surface over time. This mechanism along with insolubility of the organic additives in water accounts for the durability/efficacy of the Amicor fabrics.

All Amicor developments are thoroughly tested by independent test houses using internationally agreed test protocols. For example, we use the AATCC 100/147 protocols in the US whilst in Europe we use the Swiss Norms SNV195920/195921. The Swiss Norms are approved by the Man Made Fibres governing body- CIRFS for use as a common test procedure for comparing the antimicrobial performance of different products. All Amicor developments are tested according to enduse using these norms. Bed sheets for example will be tested after 200 wash cycles at 100°C which mimics their use cycle. The efficacy of the product is therefore guaranteed for the product lifetime.

This antimicrobial testing by independent test houses using internationally agreed test protocols forms part of the Amicor testing and certification programme. We also test each product for % composition using BS 4407. Providing that both of these tests meet with the guidelines set down by Amicor then the product is certified. This involves the customer receiving a test certificate along with a copy of the test results. These results are your guarantee of performance.

Healthcare research

Having established that the Amicor Pure fibre is able to prevent the growth of bacteria and fungi in textile articles it is important to understand why this is important, particularly the control of Fungi.

Within a healthcare environment there is strong evidence that textiles,"worn and used" in hospitals are one way in which bacterial infections are transmitted from carer to patient[4,5]. Amicor keeps all textile fabrics protected from the explosive growth of

harmful bacteria within the healthcare environment. Independent studies confirm efficacy against:
MRSA
Staphylococcus aureus
Klebsiella pneumoniae
E.Coli
Salmonella
Legionella

These independent studies have been done in the presence of various body fluids in an attempt to mimic real situations. We have tested Amicor textiles in the presence of blood, perspiration and urine and clearly shown that it continues to work in their presence[6].

Trials through hospital laundries confirm that this protection will last through 200 wash cycles at 100°C.
Work is planned with one of the NHS trusts in England and with Queens Medical in Belfast to confirm these benefits through ward trials(acute and community).

There are a number of healthcare end-uses in which odour builds up dramatically overtime and thereby adding to personal discomfort. eg:
- Bandages for under plaster casts where odour and skin trauma can result from bacteria.
- Incontinence products which can lead to odour and bedsores.
- Socks and footwear where odour and fungal infections can be a problem, particular with patients with circulatory problems and diabetes.

Amicor Plus provides re-assuring odour control during use and continues after repeated washing.

Amicor Pure bedding reduces exposure to DerP1 and *Staphylococcus aureus*. This reduces the risk of:
- Asthma
- Sinusitis
- Allergic Rhinitis
- Excema

How does Amicor Pure do this? The focus of attention in household textiles is the problems associated with house dustmites and bedmites. These generate an allergen called DerP1 which is a major constituent of the airborne dust that we breathe within our homes. DerP1 is acknowledged by the medical profession as the major cause of allergic reactions within the home. 70% of asthma cases in the home are due to this allergen. Asthma/Rhinitis/Sinusitis are all triggered by high concentrations of DerP1 allergen.

So, what is the link between asthma/bedmites and Amicor Pure's ability to prevent the development of bacteria and fungi? Bedmites are known to colonise new articles of bedding within 4 to 6 months. To do this they need 3 ingredients, which are all, provided by humans - a food source, moisture and warmth. The food source being the skin cells that we shed whilst we are in bed.. However, there is a strong fungal link with the food source. The fungi *Aspergillus repens* is needed to breakdown the skin into a food source edible by the mite. Remove the fungi and you remove the food! The allergen DerP1 is formed as part of the mites digestive processes. The DerP1 quickly becomes statically charged and airborne. We then breathe this in as we sleep.
DerP1 is acknowledged by the World Health Organisation as a major problem and they have therefore issued guidelines on the concentrations of DerP1 required to :
Sensitise someone (10 micrograms/cubic metre)
Trigger an Asthma attack once sensitised(2 micrograms/cubic metre).

Statistics showed us that Asthma is a growing problem around the world, but particularly amongst young children. There will be a number of factors contributing to this but one is certainly an increase in DerP1 concentration. The reason that more children are becoming sensitive to DerP1 can best be explained in terms of developing immune systems. When a child is borne it is protected by its mothers developed immune system. This soon decays and the child will develop its own immune system in response to its environment. Allergies develop in the same way. Exposure to high concentrations of DerP1 above 10 micrograms can therefore lead to an allergy to DerP1. Independent studies have shown that the Amicor Pure bedding maintains the DerP1 concentration at around 0.4 micrograms and hence well below the 2 and 10 microgram concentrations.

Amicor Pure bedding articles are therefore able to prevent sensitisation and minimise an asthma attack if already sensitised.

The above explanation sounds plausible but Amicor wanted to prove that these benefits could be measured. We have therefore undertaken a series of independent assessments over a 3-year period, which do indeed prove that by using Amicor it is possible to dramatically reduce the amount of DerP1 within a bedding article. Full details of these studies and the results are available from the author[7,8]. We are now trying to obtain similar independent results for the minimisation of bacteria on hospital textiles. To achieve this we are investing our time and resources into working with key organisations and suppliers to the NHS.

CONCLUSIONS

It is stressed that textiles have a vital part to play in dealing with the growing problem of Healthcare Acquired Infections, the technology exists to introduce a new generation of products that will as part of a wider scheme help to address this problem. Amicor will be part of these efforts.

One of the other major challenges facing Europe in the next 30 years is the significant change in demography. We know that we have an ageing population and that this is going to be a considerable strain not only on the health services within Europe but also on the infrastructure required to care for these old people. We have a generation of people who are growing old and who are generally more wealthy than previous generations. This same generation also has certain expectations with regard to the quality of their lives as they enter old age. There is therefore a great challenge facing the textile world and that is to develop products that meet the requirements of this demographic change. These textiles need to be smart in performance and design, and they need to be able to address the needs and expectations of future generations.

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QUALITATIVE EVALUATION OF THE BARRIER EFFECT OF TEXTILES IN USE

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ABSTRACT

International research focuses on the evaluation of barrier function and wear quality of textiles in practice. But the reasons of the measurement results are generally not examined. It is necessary to know the influences of the technological parameters such as fineness and cross-section of filaments, fineness of filament yarns, type of weave and fabric density on the pore structure in the fabric. The pore structure is examined on the cross-sections of fabrics of commercially available surgical woven fabrics of different construction. These examinations aim to assess the effect of the fabric parameters on the fabric density. Thus it will be possible to select parameters of filaments, filament yarns and fabrics to produce a better barrier effect. The relation between the barrier characteristics and the internal pore structure of woven fabrics can be determined by employing the method of optical image analysis to the structural components of woven fabrics.

INTRODUCTION

In order to provide a safe germ barrier for patients and surgeons, OR textiles (in this case woven fabrics for surgical gowns) should have a high barrier effect as well as a good wearing comfort during the whole surgical procedure. This is achieved by using special fibres (polyester microfilaments) in combination with a special finishing. Hydrophobic woven polyester fabrics are currently the only reusable materials for surgical gowns which fulfil these two contrary demands at the same time. The barrier efficiency of these woven fabrics directly depends on the arrangement of the filaments in the yarn and the construction of the woven fabric. Even though there are many different fabric structures on the market, the structural components or the pore structure of a woven fabric in combination with the barrier effect have never been basically investigated up to now using for this purpose optical methods. Therefore, researchers of the Institute of Textile and Clothing Technology have tested suitable optical investigation procedures for the geometrical analysis of OR textiles[1-7].

TESTED MATERIALS

After having analysed 29 commercial polyester filament fabrics, which are exclusively constructed in plain or twill weave, three typical fabrics are characterised in this study (Table 1). Three additional surgical fabrics are also described. The chosen fabrics are characteristic for a group of similar fabrics with regard to the filament fineness and cross-section, the fineness of filament yarns, the type of weave and the fabric density.

The plain woven fabric P 4 shows filament sections that are deformed by texturing. It has similar filament finenesses of warp and weft (Fig. 1 left). The warp cross-sections of the plain woven fabric P 5 are triangular and the weft cross sections are round (Fig. 1 centre). P 6 is a twill woven fabric with fine round warp filaments and coarse round weft filaments (Fig. 1 right).

Table 1. Parameters of the selected operating theatre textiles

sample	type of weave	fineness of filament in dtex		cross section of filament		number of filaments in the yarn		fineness of filament yarn in tex		yarn density /10cm		fabric density /8/
		warp	weft	warp	weft	warp	weft	warp	weft	warp	weft	
P 4	plain	0.85	0.85	deformed	deformed	112	102	9.5	8.5	456	370	0..55
P 5	plain	2.60	1.25	triangular	round	48	198	13.0	25.0	572	313	0..98
P 6	twill $\frac{2}{1}$	0.60	1.35	round	round	206	69	9.5	12.5	458	362	0..37

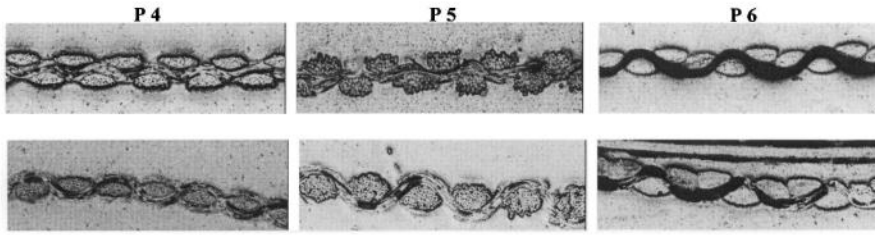


Figure 1. Light optical microscope images of the woven fabrics – above: warp section, below: weft section

METHODS OF PORE STRUCTURE DETERMINATION

It is necessary to prepare the chosen woven fabrics for optical analysis of their cross-sections. A textile sample is vertically embedded in epoxy resin in a cylindrical sample support to cut either warp yarns (= warp section) or weft yarns (= weft section). After the sample has hardened, it is smoothened and polished.

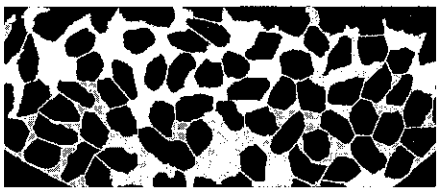
The inner pore structure is determined with images obtained transversely to the fabric plane by light-optical microscope, laser scanning microscope and scanning electron microscope. In this paper the light-optical microscopic images are discussed. Because of the resolution range, the light-optical microscope could only visualise filament distances up to 0.22 μm, which covers the range of all important bacteria (up to 0.5 μm) but not all viruses (0.01 to 0.3 μm).

The microscopic images are being assessed as two-phase images. The fabric is represented as a two-phase texture (filaments and pores). However, it is essential that the two components can be clearly identified by contrasting them sufficiently. In order to determine the geometrical parameters of the pore structure (pore width and pore length, pore area and pore form factor), we use the linear analysis and the QUANT methods of ImageC ® by Aquinto. Measurements are made in rectangular measurement fields on the measuring line. Each sample is analysed in several measurement fields to obtain a pattern repeat by sampling at random. The measured data are accumulated accordingly.

Pore width and pore length are measured using the linear analysis methods. The distances of cutting lines and the cutting direction (horizontal and vertical) are freely chosen. The distance between the individual filaments corresponds to the pore width (horizontal), and the pore length (vertical) is obtained automatically (Fig. 2). A bar diagram gives the pore distribution.

Figure 2. Determination of filament distances (chosen distance of cutting lines: 4 µm)

QUANT is an extended object-related image analysis technique for particles. Its basis is a very efficient object search algorithm, the so-called contour tracing method. This method can be applied to determine the pore areas and form factors of closed pores (Fig. 3) in accordance with the classification previously set.



pore area [µm²]	P4 and P 5	P 6
1 pink	0<...<=40	0<...<= 2
2 blue	40<...<= 80	2<...<=10
3 yellow	80<...<= 120	10<...<=20
4 green	120<...<= 200	
5 orange	200<...<= 500	20<...<=40
6 white	>500	>40

form factor: (1 = circle, 0.87 = square, 0 ≈ long stretch pore)

$$f=4\pi F/U^2$$

F: area [µm²] U: perimeter [µm]

Figure 3. Determination of pore areas and form factors

RESULTS AND DISCUSSION

Pores in the filament yarn

Pores in the filament yarn as a function of different filament cross-sections

Fig. 4 and Fig. 5 demonstrate that the pore widths are smallest in the filament yarns of P 6 where the filaments have a round cross-section.

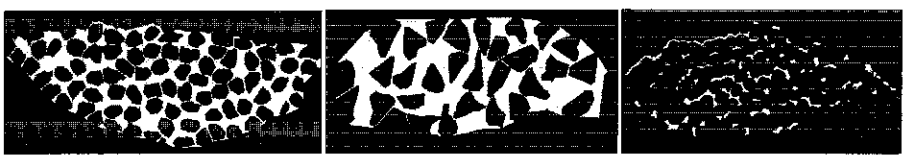


Figure 4. Examples of cross- sections of warp yarns and horizontal linear analysis (chosen distance of cutting lines: 1.2 µm)

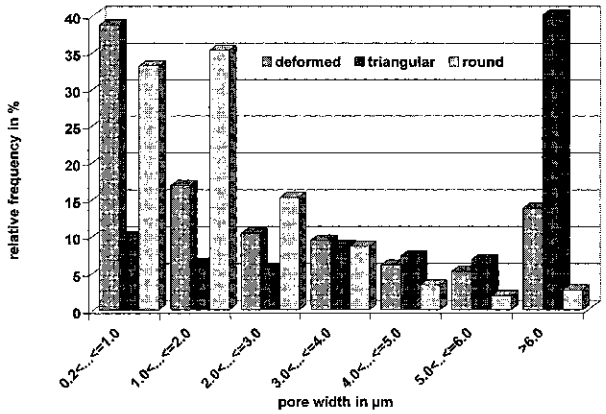


Figure 5. Relative cumulative frequencies of pore widths in the filament yarns as a function of different filament cross-sections

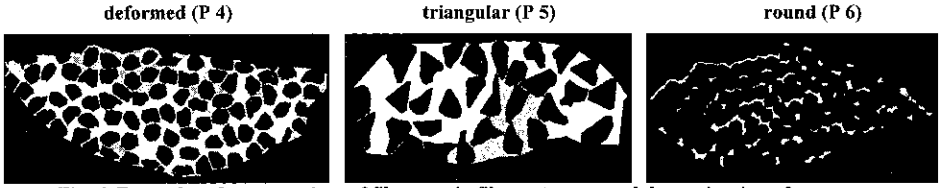


Fig. 6. Examples of cross-sections of filaments in filament yarns and determination of pore areas and form factors

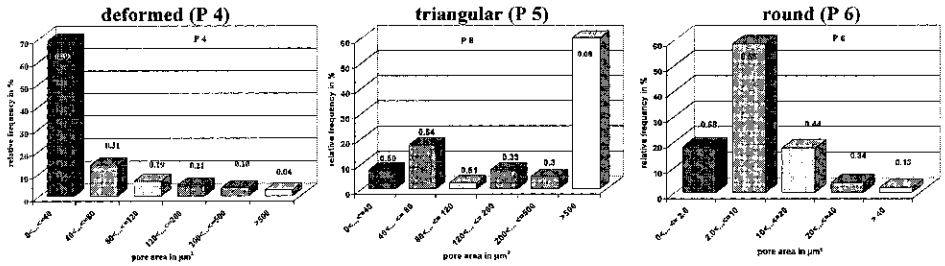


Figure 7. Relative cumulative frequencies of the pore areas and the associated form factors of the closed form areas (plotted against the bars) - P 5 and P 6 warp section

The yarn with deformed filament cross-sections in P 4 has 13.7 % share of pore widths larger than 6 µm. The coarse filaments with triangular cross-sections in P 5 produce a pore share of 45.9 % for pores larger than 6 µm. For the warp yarn of P 6, which consists of round micro filaments, it has been found that only 2.6 % of all pore widths are larger than 6 µm and there are no pore canals, i.e., the barrier effect of textile structure prevents the transmission of bacteria (Fig. 5).

The analysis of the pore area (Fig. 6, 7) confirms the results obtained by the linear analysis. P 4 has 31.2 % of pore areas larger than 40 μm^2, while the share of P 5 is 92.5 %. For example in Fig. 6 centre the white continuous pore area covers about three

quarters of the warp yarn. In P 6 there is only 1.9 % of all pores larger than 40 μm^2. The more larger the pore area, the less circular it is.

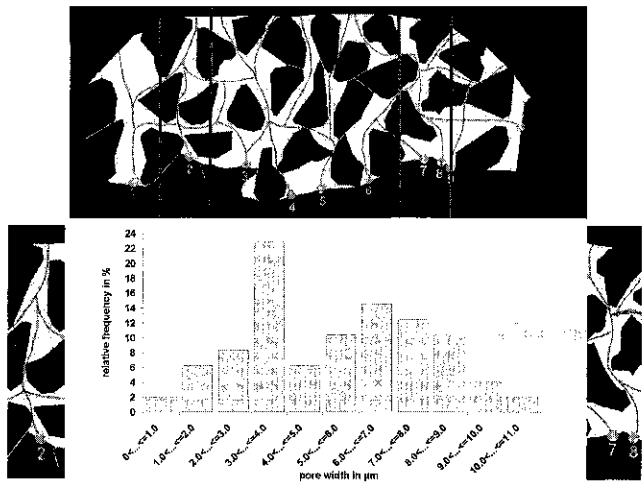


Figure 8. Selected pore channels in a warp yarn of P 5

P 5 does not have a barrier effect for bacteria. For this purpose, the transfer of micro organisms is applied to particular image sectors. It is assumed that there are transfer paths for micro organisms if there are continuous pore channels. Ten sections of warp and weft yarns of P 5 have been made as illustrated in the example shown in Fig.8. All sections examined were continuous, i.e., all of the pore surface could be marked with the chosen colour with the help of the program. The pore widths have been measured for the individual pore canals. These measurements show that the continuous pores present a considerable health hazard.

Pores in the filament yarn as a function of different filament fineness

Yarns with coarse round filaments and fine round filaments differ in the pore structure. In coarse filaments 42.4 % of all pores are larger than 6 µm. In the case of finer filaments, this applies only to 2.5 % of pores.

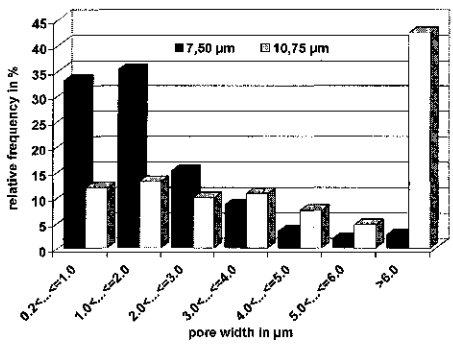


Figure 8. Relative cumulative frequencies of the pore widths in the filament yarn as a function of different filament fineness

Pores resulting from the fabric structure

Plain weave (Fig. 1):

The weft yarns are fairly stretched within the fabric, while the warp yarns have a high warp insertion. In P 4 (warp section), the warp yarns are overlapping each other so that three filament yarns put on top of each other partially. This may improve the particle barrier effect.

Twill weave (Fig. 9):

On the left side it is shown that in the twill weave (P 6) the pores between two weft yarns (12.6 tex) are large because the yarns are comparatively thick. Although thinner filament yarns are used as warp yarns, the spaces between the filament yarns are wide as well (Fig. 9 right). This applies to almost all pores between two warps (two wefts). The maximum filament yarn distance is 81.33 µm.

P 6 (weft section) **P 6 (warp section)**

Figure 9. Pores between filament yarns in twill weave (P 6)

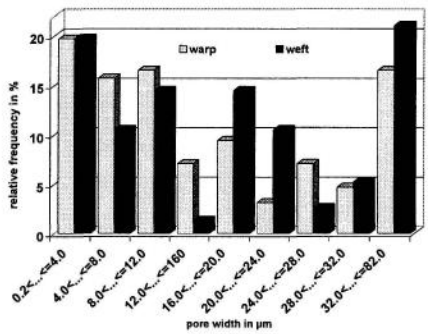
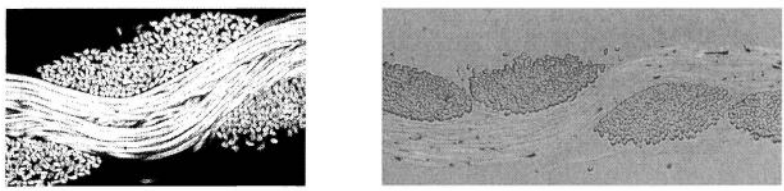


Figure 10. Relative cumulative frequencies of the pore width classes in the warp and weft section resulting from the fabric structure[6]



warp section **weft section**

Figure 11. Pores resulting from the fabric structure - P 3[5]

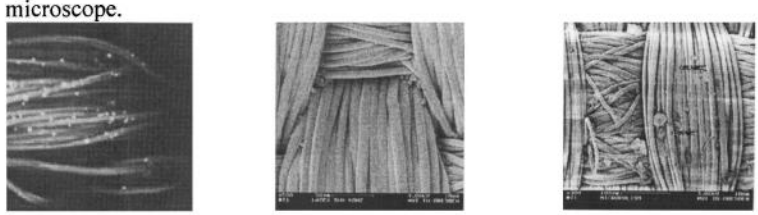
Additionally, another twill weave fabric K 2/2 (warp: 10 tex, 730 yarns/10 cm, weft:

20 tex, 590 yarns/10 cm) has been examined[5]. The low weft yarn density and the coarse weft yarns also result in large pore spaces in the weft section. In the warp section, the two thinner warps (10 tex) are pressed tightly against each other (Fig. 11).

Penetration tests

The results of structural barrier effect are compared with the results of penetration tests. Synthetic blood or particle loaded liquids containing micro spheres comparable with the sizes of bacteria are used. The time necessary to soak the fabric with liquids or the contamination on the back of the fabric are determined. Here are two examples:

1. micro spheres – Fig. 12 (left)
   Fluorescent micro spheres with a mean diameter of 1 µm are used. They have a round shape and are comparable to the size of *staphylococcus aureus*, a typical bacteria in the operating theatre. The contamination on the back of the fabric is affected by the reaction time, the type of solvent or DMSO (dimethyl sulfoxide) and the cylindrical roll-off-movement on the surface of the sample.
2. Latex micro spheres and micro polish suspensions - Fig. 12 (centre and right).
   Latex micro spheres with a mean diameter of 5 µm or micro polish particles with a mean particle size of 3 µm are used. Test suspensions have been strongly diluted with distilled water. A micro pipette is used to apply 20 µl of this suspension onto the right side of the woven fabric. Subsequently, the sample is subjected to a pressure of 0.33 N/cm^2 (= lightly leaning on the fore arm) for 30 minutes at the Zwick 1445. The micro spheres and micro polish particles which have been appeared on the back of the fabric are made visible with the scanning electron microscope.



after 4 hours | **after 30 min pressure of 0.33 N/cm²** | **after 30 min pressure of 0.33 N/cm²**

Figure 12. Micro spheres of 1 µm (left), latex micro spheres of 5 µm (centre) and micro polish particles of 3 µm (right) on the back of the fabric after penetration

Moreover, the results of the penetration tests with micro spheres and the determination of the contamination on the back of the fabric confirm that most of the fabrics have no barrier effect (Fig. 12).

PORE STRUCTURE IN USE

A new project started in January 2003. It will last for 2.5 years. It deals with surgical gowns in use. Among others, reusable gowns of different construction are used in the University Hospital of the Technische Universität Dresden in the following departments:

- orthopaedics
- trauma and reconstructive surgery

After having been used in the operating theatre, the gowns are cleaned in the laundry, sterilised and reused in the operating theatre. It is the aim of this project to determine the actual service life within which the surgical gowns are an effective barrier between the source of infection and the healthy person. The coded surgical gowns are tested in accordance with DIN EN 13 795-2 (2003) after a fixed number of reprocessing (cleaning and sterilising) cycles to ascertain the effect of reprocessing and use in the operating theatre. Moreover, the barrier effect is assessed. The methods described in the presentation are employed for this purpose. The barrier effect will decrease due to the high mechanical stress and the associated effect on the fabric structure. This process is quantified and a comparison is made with the original condition of the fabric. As the organisation of the logistics requires significant commitment of time, unfortunately no results have been obtained so far. The expected results will be presented during the tests and after their completion.

CONCLUSIONS

1. The image analysis methods linear analysis and QUANT of ImageC® by Aquinto are well suited to characterise the pore structure of woven fabrics. They allow good measurement of the horizontal and vertical pore spaces, pore areas and form factors of closed pores with sufficient certainty.
2. It is necessary to optimise commercially available surgical woven fabrics which are made of PES filament yarns because they often cannot fulfil the barrier function. The penetration of particle-loaded liquids can be explained by the pore geometry.
3. Pores are found both in the filament yarn and in the woven fabric. Their size, geometry and number depend on the yarn and fabric parameters.
4. Round cross-sections with fine fineness of the filament yarns are favourable for a maximum packing density. Triangular filament cross-sections and coarse filaments result in the widest pore spaces.
5. The type of weave in connection with the yarn density is decisive for a better barrier effect. Twill weave is particularly critical since it may have large pores between two weft yarns in the crossing points.
6. It is the objective to model the theoretical density of the woven fabric. Assuming model fabrics that are woven from filament yarns with a calculated circular cross section and with warp and weft yarn densities of 100 % according to[6], the 3D fabric structure is simulated. Subsequently, the yarn cross-sections and the yarn insertion are varied to improve fabric density.

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REDUCING MICROBIAL CONTAMINATION IN HOSPITAL BLANKETS: A CONTRIBUTION TO COMBAT NOSOCOMIAL INFECTIONS (HOSPITAL INFECTIONS)

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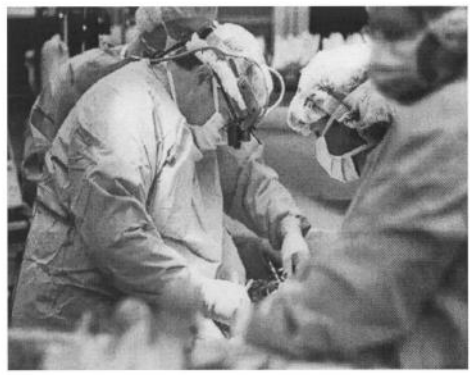
ABSTRACT

Regardless of many precautions that hospitals take today, 5 to 10 % of the hospital patients in Belgium will develop a nosocomial infection during their stay in the hospital. According to Dr. Carl Suetens of the NSIH (Nationale Surveillance van infecties in hospitalen) the amount of patients which catch a nosocomial infection in Belgium would be estimated around 75,000 people a year. It is estimated that 1% (750) of these patients die of the direct consequences of a nosocomial infection. The remaining 99% will not come away unharmed because nosocomial infections can counteract the results of an operation, or can cause permanent invalidity.



The medical industry is challenged by the presence of microorganisms and the negative effects they cause. Cross contamination, deterioration, defacement and odours are all dramatic effects which occur from the microbial contamination of surfaces as varied as carpeting to medical nonwoven fabrics. These surfaces can also act as a microbial "harbor" as most offer ideal environments for the proliferation of micro-organisms that are harmful to humans and textiles. The ability to make surfaces resistant to microbial contamination has advantages in many applications and market segments. This is especially true in medical markets where many products have contributed a higher degree of aseptic sophistication.

Surfaces used in medical applications have unique microbial problems and their control is a complex task. The microbiological integrity of surfaces has been the object of numerous studies ranging from bacterial loading of carpeting to the evaluation of the barrier properties of nonwoven fabrics. Test data generated with surfaces treated with the ÆGIS Microbe Shield Technology, supports the fact that it contributes positively to the reduction of microorganisms

in the medical environment. This contribution has been part of the medical communities actions aimed at improving the hygienic nature of their environment as they take steps towards asepsis.

NOSOCOMIAL INFECTION

Nosocomial Infection is a serious issue for healthcare facilities. According to recent articles, 1.8 million Americans contract nosocomial infection from hospitals every year. 20,000 patients died in 1998 as a direct result of nosocomial infection and 70,000 died from complications caused by infection. The cost of treating nosocomial infection in the United States is estimated at $4.5 billion a year. Controlling infection in an environment which is contaminated by the nature of its function is difficult at best and requires a multifaceted approach.

Will hospital blankets, protected by the ÆGIS Microbe Shield Technology, make an end to nosocomial infections? No.

Will hospital blankets, protected by the ÆGIS Microbe Shield Technology, control bacterial and fungal contamination on the blanket? Yes.

Will the use of hospital blankets, protected by the ÆGIS Microbe Shield Technology, be a positive step toward asepsis in the patients' immediate environment? Yes.

Is the use of hospital blankets, protected by the ÆGIS Microbe Shield Technology, a component of practicing reasonable care? Yes.

VARIOUS STUDIES

Blanket studies

The desired performance of an antimicrobial treated surface is to significantly reduce levels of bacterial and fungal contamination, when compared to a similar untreated surface. Controlling and/or killing the microorganisms commonly associated with infections is a key component to maintaining an aseptic surface. Primary considerations regarding the selection of an antimicrobial are: its safety to the building occupants, that the antimicrobial activity remains unaffected by common cleaning procedures and that the antimicrobial is not susceptible to inductive or mutative adaptation. Those surfaces that are handled by the staff, such as blankets, should also be expected to retain all of the original handling and appearance characteristics.

ÆGIS Environments has made a study that compares blankets that were treated with the ÆGIS Microbe Shield technology and blankets that were untreated. In any environment, blankets can become a haven for bacteria. These bacteria usually represent a spectrum of Gram positive and Gram negative organisms capable of producing infections, staining, deterioration and odours.

In a hospital environment, fever and sweat are common and an excellent source of bacterial contamination. In an effort to evaluate the effects that a hospital environment has on treated and untreated blankets, two separate studies were undertaken. The first 'Simulation Study' was initiated to simulate the types of exposures blankets receive when in use on a feverish patient. The second 'In-use Study' was initiated to determine the effectiveness of the antimicrobial on blankets when stored and used within a care facility.

Simulation study

The first study was performed with treated and untreated blankets that were cut into 5 by 6 inches samples with exact weight of 5.2g per sample. Each sample was labeled and attached to a plastic bag. These samples were used to uniformly towel off the sweat from healthy male subjects after one hour of high endurance exercise. The samples were re-placed into each bag and incubated at 37° C for 3 weeks. The purpose of this testing was to simulate blanket exposure to febrile, diaphoretic patients.

Initial bacterial retrievals before incubation were performed using the BioBurden 100 (BB 100) test procedure to determine active bioload at the beginning of incubation. Each sample was cut into a 2.4g swatch of cloth that was placed in a sterile flask containing 100ml of phosphate buffer ($KHaPO_4$). The flask was then agitated for 30 minutes to release bacteria. After this time the bacteria were plated into nutrient agar and incubated at 37° C. After several days, the plates were counted and the bacteria were characterised. The results of this study show that the treated sample had 1000 CFU/cm^2 (colony forming units per square centimeter) of bacteria compared to the untreated sample which had three times the amount of bacteria 3000 CFU/cm^2 representing a 67% reduction in microorganisms on the blanket. The types of organisms represented in the samples were *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Micrococcus* and *Bacillus*, typical skin and soil isolates.

The bacterial retrievals were repeated after 40 days of incubation at 37° C. A bioburden of 1051 CFU/g was recorded on the untreated sample while the treated sample showed a bioburden of 283 CFU/g which verified a significant 73% reduction in microorganisms. The rate of bioburden reduction on the treated samples show good correlation to the samples initially tested with 1 day of incubation.

The same samples were then subjected to an odour panel of ten people. These men and women were asked to independently rate the samples based on their perceived odour and rank the level of odour on a 0 - 10 scale with 10 representing a putrid odour and 0 representing no odour. These rankings were averaged for all treated and untreated samples. The untreated samples averaged a score of 3.3 while the treated samples averaged a score of only 1.5. While the odour study is a qualitative test and not a quantitative measure, it does provide insight that the reduction in bioburden does significantly affect the observable odour level.

In-use study

The second study was performed with treated and untreated blankets that were put in use in a 24 hour care facility in North Carolina. All of the blankets were labeled with identification thread at the foot of the blanket. Black thread indicated a blanket was treated and red thread indicated a blanket was untreated. Eight of the ten blankets were stressed by putting them into use on beds at the care facility. All of the blankets were put into service on the same day at approximately the same time. All of the blankets were removed from service when one of the test blankets was soiled by a patient (the soiled blanket was a treated blanket). All of the test blankets were individually wrapped in plastic and sent to the laboratory to initiate retrievals and testing.

Initial bacterial retrievals were performed on the stressed and non-stressed blanket samples to determine active bioload using the BB 100 test procedure. Three 2.5g swatches

were cut from each blanket using aseptic techniques. The head sample was taken 12 inches from the top of the blanket - centered from the sides, the foot sample was taken 12 inches from the bottom of the blanket - centered from the sides, the middle sample was taken from the center of the blanket. Each sample of cloth was placed in a sterile flask containing phosphate buffer. The sample was then agitated for 30 minutes and total bacteria were retrieved on nutrient agar plates. For these samples the results are presented in the form of colony forming units per gram of blanket sample (CFU/g). Using CFU/g the percent bacterial reduction in the treated samples versus the untreated samples is calculated and reported.

The results from the non-stressed blankets indicate an average of 1120 CFU/g for the untreated head samples compared to an average 280 CFU/g for the treated head samples, indicating a 75% reduction in organisms on the head samples of the treated blankets. The untreated middle samples averaged 1720 CFU/g while the treated middle samples averaged 400 CFU/g, indicating a 77% reduction in organisms on the middle samples of the treated blankets. The untreated foot samples averaged 800 CFU/g while the treated foot samples averaged 200 CFU/g, indicating a 75% reduction in organisms on the foot samples of the treated blankets (Table 1). The reduction of bioburden on the nonstressed blanket indicates the effectiveness of the ÆGIS Microbe Shield technology in protecting hospital blankets during distribution and storage.

Table 1. Nonstressed samples

Non-stressed Samples	Head	Middle	Feet
% Bacterial reduction	75%	77%	75%

The results from the stressed blankets indicate bioburden levels over ten times higher than those exhibited by the non-stressed blankets. The stressed blanket samples indicated an average of 16000 CFU/g for the untreated head samples compared to an average 6600 CFU/g for the treated head samples. Comparison of the averages of the untreated blanket to the averages of the treated blanket indicates a 59% reduction in organisms on the head samples of the treated blankets. The untreated middle samples averaged 12000 CFU/g while the treated middle samples averaged 4700 CFU/g, indicating a 61% reduction in organisms on the middle samples of the treated blankets. The untreated foot samples averaged 7560 CFU/g while the treated foot samples averaged 440 CFU/g, indicating a 94% reduction in organisms on the foot samples of the treated blankets (Table 2). The reduction of bioburden on the stressed blanket samples indicates the effectiveness of the ÆGIS Microbe Shield technology in protecting hospital blankets during actual handling and use.

Table 2. Stressed samples

Stressed Samples	Head	Middle	Feet
% Bacterial reduction	59%	61%	94%

Additional studies

There are several bioburden studies in the literature comparing fabrics treated with the ÆGIS Microbe Shield technology with untreated fabrics. A study, performed jointly by American Hospital Supply (now Baxter Healthcare) and (attachment A) Dow Corning Corporation, generated data that is relational to the environment and microorganisms likely to be encountered by blanket use in hospital environments.

In the series of tests the nonwoven treated and untreated barrier drapes were tested using clinical wound and urine isolates to determine the effectiveness of the ÆGIS Microbe Shield technology in controlling the growth of microorganisms on the substrate. In this testing it was shown that The ÆGIS Microbe Shield technology reduced wound isolate bacterial loading of the drape by 93.6%, 99.7% and 99.5% while reducing the urine isolate bioburden on the drape by 99.9% and 98.6%.

Another series of tests were performed to show the percent of bioburden reduction on ÆGIS Microbe Shield technology treated nonwoven fabric when the fabric was inoculated with buffered phosphate, saline and serum. The treated fabric showed a 99% reduction of *Klebsiella pneumoniae* when delivered using the buffered phosphate, 90% reduction of *Klebsiella pneumoniae* when delivered using saline and a 90% reduction of *Klebsiella pneumoniae* when delivered with serum.

CHOOSING THE RIGHT ANTIMICROBIAL

Selecting the right product and process for the eventual end-use include a wide variety of criteria. These include regulatory compliance, toxicity to people and the environment, feature and application specific performance, basic integrity of the product and costs. The ability to determine the performance criteria of these customised textiles is not simple and must include a complete understanding of the end-use requirements and the strengths and weaknesses of the testing techniques that are to be used.

The selection of an antimicrobial should be done by considering:

1) Adopting a non-leaching antimicrobial that doesn't pose the risk of crossing the skin barrier or negatively affecting the normal microbial flora of the skin. If it creates a "zone of inhibition" or must integrate into the all to have function, it leaches or moves and has the potential to cause problems to people and the environment.

2) Adopting an antimicrobial technology with a proven history of use. This will help shorten the timelines in bringing products with an antibacterial/antifungal/ odour-reducing, antimicrobial feature to market.

3) Adopting a non-leaching antimicrobial that doesn't pose the risk of creating adaptative resistant microorganisms.

4) Adopting an antimicrobial technology that is registered with the EPA, the EU and other regulatory agencies for the specific product it is applied to.

5) Adopting an antimicrobial technology that can be tested for proper application at the mill or at the retailers. A verifiable quality assurance programme should be a key component of any application process.

6) Adopting an antimicrobial technology that has technical and marketing support.

Numerous retail buyers have stated that the antimicrobial/antibacterial "feature" is quickly moving to a standard requirement for the products that they buy. Manufacturers that don't currently treat fabrics with a durable antimicrobial finish should consider shielding their products from eroding value by incorporating microbial control. As manufacturers look to enhance the value of their products they should recognise antimicrobial finishes as a feature with a future and the future is now.

Antimicrobial finishes

All antimicrobials do not work the same principle. The vast majority of antimicrobials work by leaching or moving from the surface on which they are applied. This is the mechanism used by leaching antimicrobials to poison a microorganism. Such chemicals have been used for decades in agricultural applications with mixed results. Besides, the challenges of providing durability for the useful life of products, leaching technologies have the potential to cause a variety of other problems when used in textiles. These leaching properties can contact the skin and potentially affect the normal skin bacteria, cross the skin barrier, and/or have the potential to cause rashes and other skin irritations. A more serious problem with leaching technologies is that they allow for the adaptation of microorganisms.

An antimicrobial with a completely different mode of action than the leaching technologies is a molecularly-bonded unconventional technology. The bound unconventional antimicrobial technology, an organofunctional silane, has a mode of action that relies on the technology remaining affixed to the substrate - killing microorganisms as they contact the surface to which it is applied. Effective levels of this technology do not leach or diminish over time. When applied, the technology actually polymerises with the substrate making the surface antimicrobial. This type of antimicrobial technology is used in textiles that are likely to come into human contact or where durability is important. Dr. M. Bourgeois and researchers at the "Institute Textile de France" in Lyon have also accomplished this type of surface modification by electron beam grafting of acrylic monomers with quaternary ammonium compounds to hydroxyl active surfaces. In either case, durability to wear and laundering with broad-spectrum antimicrobial activity have been demonstrated.

Antimicrobial function and adaptation

Antimicrobials primarily function in two different ways. The conventional leaching types of antimicrobials leave the textile and chemically enter or react with the microorganism acting as a poison. The unconventional bound antimicrobial stays affixed to the textile and, on a molecular scale, physically stabs (the lipoprotein components of the membrane) and electrocutes (the anionic biochemicals in the membrane) the microorganism on contact to kill it. Like an arrow shot from a bow or bullet shot from a gun, leaching antimicrobials are often effective, but are used up in the process of working, wasted in random misses, or complexed by other chemicals in the environments of use and abuse. Some companies incorporate leaching technologies into fibers and slow the release rate to extend the useful life of the antimicrobial, even adding to them chemical binders and claiming they are now "bound." Whether leaching antimicrobials are extruded into the fibre, placed in a binder, or simply added as a finish to fabrics or finished goods, they all function the same. In all cases,

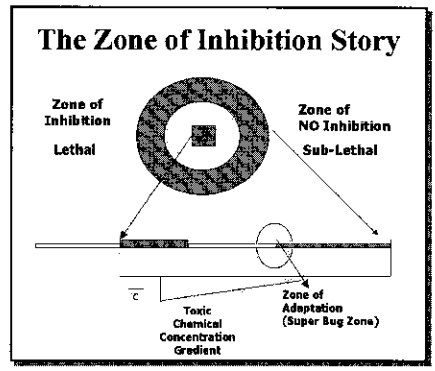


Figure 1. Zone of inhibition

Leaching antimicrobial technologies provide a killing field or "zone of inhibition." This zone exists in real-world uses if it is assumed that the right conditions are present for leaching of a lethal dose at the time that it is needed. The zone of inhibition is the area around the treated substrate into which the antimicrobial chemistry leaches or moves to, killing or inhibiting microorganisms. This killing or inhibiting action of a leaching antimicrobial is witnessed when an AATCC 147 test or other zone of inhibition test are run. These tests are used to measure the zone of inhibition created by a leaching antimicrobial and clearly define the area where the antimicrobial had come off the substrate and killed the microorganisms in the agar. Such a phenomenon can be explained in Fig. 1a and 1b. Figure 1a presents graphically a typical zone of inhibition test method. The blue area represents a textile material treated with a leaching antimicrobial. The zone of inhibition is represented by the clear zone surrounding the substrate and the sublethal zone is shown in gray. The area at which the zones merge is presented as the zone of adaptation.

Microbes are living organisms and, like any living organism, will take extreme measures to survive. Microorganisms can be genetically mutated or enzymatically induced into tougher "super-strains" if they are exposed to sublethal doses (exposed to - but not killed) of antimicrobial agents. This ability of microorganisms to adapt to potential toxicants has been recognised in the medical community for years. Sublethal levels of antibiotics are generated in the patients who discontinue taking antibiotics once their symptoms subside instead of continuing through to the end of the period prescribed by the physician. The exposure of the microbe to a sublethal dose of an antimicrobial can cause mutation of their genetic materials allowing for resistance that is then replicated through the reproductive process creating generations of microorganisms that are no longer affected by the chemistry. This phenomena is of serious concern to the medical community and food processing industries and should be a serious consideration for the nonwoven textile industry as it chooses the antimicrobials to which it will be exposing the public and their workers.

As with any chemistry that migrates from the surface - a leaching antimicrobial is

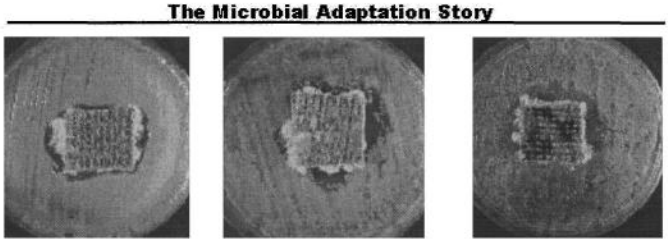


Figure 2. Figure 3. Figure 4.

strongest in the reservoir, or at the source, and weakest the farther it travels from the reservoir. The outermost edge of the zone of inhibition is where the sublethal dose can be found—this is known as the zone of adaptation (Fig. 1). This is where resistant microbes that have been produced by leaching antimicrobials are found. The ongoing challenge for leaching technologies is the control of the leach rate from their reservoir such that a lethal dose is available at the time that it is needed.

This is demonstrated in the following images from experiments where a microbe sample was taken from the outer edge of the zone of inhibition of a common leaching antimicrobial from treated carpet fibre (Fig. 2) and used to inoculate a new test plate. The second test plate (Fig. 3) shows the adapted micro-organisms growing within the zone of inhibition. The adapted organism is taken from the second plate and used to inoculate a third plate (Fig. 4). The microorganism used to inoculate this plate is fully adapted to the leaching antimicrobial and has overgrown the fabric. The ghost zone indicates the organism being slowed but not controlled by the leaching toxicant. All this occurred within just two generations of the test organism under these test conditions.

A significantly different and much more unique antimicrobial technology used in the textile industry does not leach but instead remains permanently affixed to the surface on which it is applied. Applied in a single stage of the wet finish process, the attachment of this technology to surfaces involves two means. First and most important is a very rapid process, which coats the substrate (fabric, fibre, etc.) with the cationic species (physisorption) one

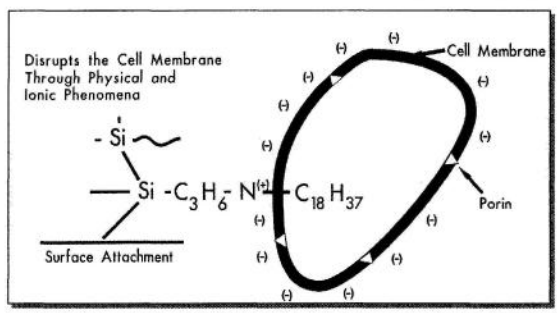


Figure 5. Bonded chemical

molecule deep. This is an ion exchange process by which the cation of the silane quaternary ammonium compound replaces protons from water or chemicals on the surface. The second mechanism is unique to materials such as silane quaternary ammonium compounds. In this case, the silanol allows for covalent bonding to receptive surfaces to occur (chemisorption). This bonding to the substrate is then made even more durable by the silanol functionality, which enables them to homopolymerise. After they have coated the surface in this manner, they become virtually irremovable, even on surfaces with which they cannot react covalently (Fig. 5).

Once polymerised, the treatment does not migrate or create a zone of inhibition so it does not set up conditions that allow for adapted organisms. Because this technology stays on the

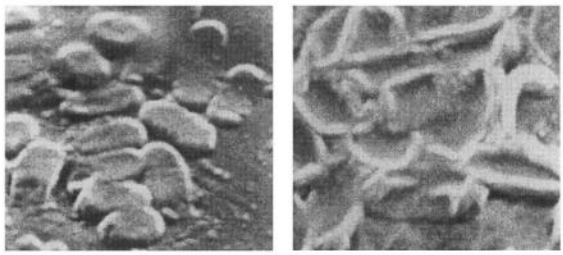


Figure 6. Untreated nonwoven — Treated nonwoven-EM 5700/5772 *Escherichia coli*

substrate, it does not cross the skin barrier and neither affects normal skin bacteria nor causes rashes or skin irritations. This organofunctional silane technology has been used for over two decades to treat surfaces from leather and foams to virtually all types of fabrics and is not consumed by the microorganism. It does not poison the microorganism. When a microbe contacts the organofunctional silane treated surface of the fabric, the cell is physically ruptured by a sword-like action and then electrocuted by a positively charged nitrogen molecule (Fig. 6). This antimicrobial technology has been verified by its use in consumer and medical goods including socks, surgical drapes and carpets in the USA, Asia and other areas in the world. This technology has been used for nearly twenty-five years without any human health or environmental problems inside manufacturing facilities or in actual end-use situations.

CONCLUSIONS

These data generated by university, medical and industrial laboratories represent some of the most extensive microbiological work performed on antimicrobial treated substrates for use in the medical community. Both studies clearly show that blankets protected by the ÆGIS Microbe Shield technology have a significantly lower bioburden and will present less of a risk in the patient environment. Historical data generated by American Hospital Supply and Dow Corning Corporation support these findings. Reducing microbial contamination by treating hospital blankets with the ÆGIS Microbe Shield Technology will be a step forward in the combat against nosocomial infections.

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DURABLE AND RECHARGEABLE BIOCIDAL TEXTILES

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ABSTRACT

Textile materials, including natural and synthetic fibers, are good media for growth of microorganisms, particularly the drug-resistant bacteria, which have caused great concern to public health. Biocidal properties should be a necessary feature for medical-use textiles. Biocidal functions, different from biostatic functions, include sterilization, disinfection, and sanitization in an order of the strength. According to guidelines from the US Centers for Disease Control and Prevention (CDC), medical use biocidal functions should be at least at the disinfection level, which can inactivate most infectious microorganisms. In addition, biocidal functions on textile materials should survive repeated laundering if used as uniforms, linens and even reusable surgical scraps and gowns. Among the currently investigated antimicrobial materials, only N-halamines have shown the capability of providing fast and total kill against a wide range of microorganisms without causing resistance from microorganisms. Furthermore, halamine structures can be recharged by chlorine bleaching, a process recommended by CD as well. Thus, biocidal textiles containing the halamine structures have been developed. Recent studies in biocidal polymers have resulted interesting progresses in incorporating halamines to all synthetic fabrics that are widely used as medical and other professional clothing materials. Chemistry and properties of the new processes have been discussed in this presentation.

INTRODUCTION

In recent years protection of healthcare workers from cross-transmission of infectious diseases, particularly blood borne viruses such as HIV and Hepatitis B, has become extremely urgent and important to medical professionals [1-2]. Medical protective gear for doctors and nurses including gowns, masks, and gloves are currently serving as barriers to the diseases and are insufficient in preventing the transmissions of the diseases. Recent outbreaks of Severe Acute Respiratory Syndrome (SARS) have further indicated that the barrier materials may not be able to provide sufficient protections against this disease since a large number of SARS patients are healthcare workers. In addition, researchers have revealed that textiles are good media for hosting microorganisms and therefore, are potentially responsible for the disease transmission [3]. Moreover, spreading of multidrug-resistant bacteria in healthcare facilities is threatening not only safety of healthcare workers but also publics. One drug-resistant microorganism, mecicillin-resistant *Staphylococcus aureus* (MRSA) was found not only existing but also surviving for a long period of time on all of textile materials in hospital environment [3-5]. No doubts, textile materials are responsible for disease transmission and spreading of the new strains of the diseases from the main sources to elsewhere [3]. On the other side, textile materials, as necessary materials for clothing and daily life, are possible means for prevention of infectious diseases and pathogens, if they become antimicrobial. Thus, the research and development of antimicrobial textiles, particularly the medical textiles for healthcare providers and patients are important and necessary.

MEDICAL USE TEXTILES

What are the ideal protective textiles for medical workers? A quick and brief answer is antimicrobial textiles, or more specifically the biocidal textiles. The biocidal materials are able to kill and eliminate the growth of microorganisms, and can therefore protect wearers of the textiles from biological attacks. Biocidal functions are completely different from biostatic functions that only inhibit the growth of microorganisms on textiles. Biostatic functions are usually employed in preservation of textile arts in museum or odor-control of the materials, but cannot prevent transmission of diseases due to the limitation of functions.

It is commonly believed that the ideal biocidal textile materials for medical use should posses the following features: 1) rapid inactivation of a broad spectrum of microorganisms; 2) non-selective and non-immutable to pathogens; 3) non-toxic and environmentally friendly; 4) durable to repeated washes; and 5) easy to be recharged in laundering or disinfection processes. In addition, the recharging agents should be non-toxic, available at home, and compatible with our laundering chemicals such as detergents or bleaching agents. Antimicrobial textile material was first developed in 1867 by Lister who demonstrated the relationship between fibrous materials and diseases [6]. Since then, many innovative antimicrobial materials have been developed [7-10].

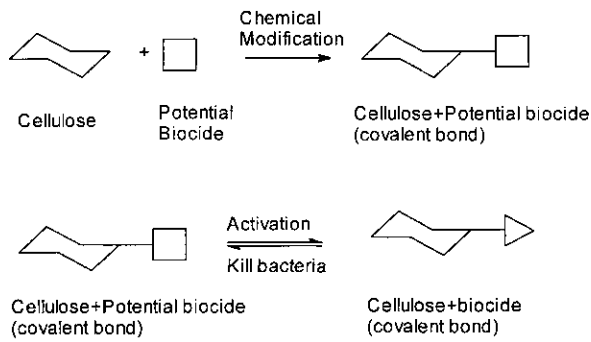

Figure 1. Regeneration principle[14] (Reproduced from reference 14, copyright American Association of Textile Chemists and Colorists)

Rechargeable biocidal functions

In 1962 Gagliardi proposed a model in making antimicrobial textiles, named regeneration principle[11]. Although the model was presented over thirty years ago, there has been little reported success in textiles until recently. However, this principle has provided an important approach in the design of this innovative functional finishing. Antimicrobial functions on textiles, different from other functional finishes on textiles, normally consume biocidal agents incorporated into fibres. Therefore, to achieve durable and rechargeable antimicrobial functions reversible reactions and house-hold recharging agents were considered in this research.

Chlorine bleach is a registered biocide and has been used as a disinfectant for decades without any reported resistance generated from any microorganisms. But, it is quite corrosive and toxic, particularly with concerns of producing carcinogens (such as $HCCl_3$) in water. However, some of chlorine derivatives, i.e. halamine compounds, though possessing similar biocidal properties as chlorine, are more environmentally friendly and thus widely used in swimming pools and even drinking water disinfection [12-13]. Halamines inactivate microorganisms by oxidation mechanisms rather than biological functions, and wide usage of them could result in less concern on drug-resistance of diseases. If the halamine compounds can be covalently connected to polymers, a reversible redox reaction can then be implemented on solid materials. The design of modification of textiles, activation or regeneration of halamine structures, and inactivation of microorganisms is expressed by a regeneration principle (Fig. 1)[14-15].

According to the mechanism of the biocidal function and regeneration process, diluted chlorine bleach solutions serve as both activation and regeneration agents of the biocidal functions. By using the chlorine bleaching process, the potential biocidal groups grafted on cellulose, i.e. amide or imide N-H bonds in hydantoin rings, will be converted to biocidal halamine structures, meanwhile the textiles materials are sterilised. It provides a convenient way for activation and regeneration of biocidal functions, and is the best fit for medical use textiles since they are commercially laundered with chlorine bleach. Many of these halamine structures have been reviewed and investigated for water disinfection purposes [12]. Recent development of halamine polymers has brought in many applications of the chemical equations [13].

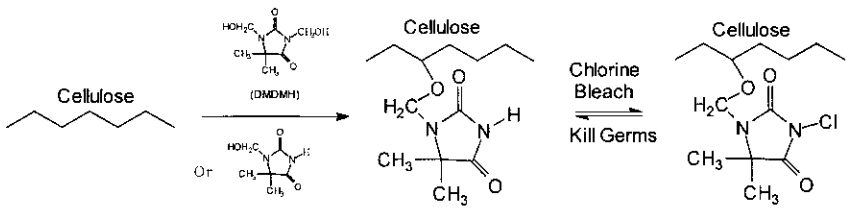

Figure 2. Antimicrobial finishing on cellulose [14-15]

Rechargeable biocidal finishing of cellulosic fabrics

Monomethylol or dimethylol derivatives of 5,5-dimethyl hydantoin were first employed in grafting the heterocyclic ring to cellulose [14-15]. When chlorine atom replaces hydrogen on N-H bond, the N-Cl bond is formed and stabilised by the vicinal carbonyl groups on the grafted dimethyl hydantoin ring (Fig. 2). The stability of N-Cl bonds on halamines contributes to the durability and stability of antimicrobial properties on chlorinated fabrics, with evidence that the bleached fabrics could retain the antimicrobial properties for more than six months in conditioning room (at 21°C and 65% relative humidity). After each laundering, the fabrics treated with dimethylol-5,5-dimethylhydantoin (DMDMH) or monomethylo-5,5-dimethylhydantoin (MDMH) could be recharged by chlorine bleaching because of presence of predominant imide N-Cl bonds that can be washed off by detergents (reverse reaction in Fig. 1).

Table 1. Biocidal results of fabrics treated by 2% and 6% of DMDMH [15]

Fabric*	Microorganism	Log Reduction of Bacterial Challenge	
		2% DMDMH	6% DMDMH
Cotton	*E. coli*	6	6
Cotton/PET		6	6
Cotton	*Staph. aureus*	6	6
Cotton/PET		6	6
Cotton	*Salmonell*	6	7
Cotton/PET	*choleraesuis*	7	6
Cotton	*Shigella*	6	6
Cotton/PET		6	7
Cotton	*Candida albicans*	2	6
Cotton/PET		6	6
Cotton	*Brevibacterium*	8	8
Cotton/PET		8	8
Cotton	*Pseudomonas*	6	6
Cotton/PET	*aeruginosa*	6	6
Cotton	*Methicillin-resis.*	/	3
Cotton/PET	*Staph. aureus*	/	6
Cotton	*Vancomycin resis.*	/	6
Cotton/PET	*Enterococcus*	/	6

AATCC test method 100. contact time: 2 minutes.
* plain woven pure cotton fabric and polyester/cotton (65/35) plain woven fabric. (Reproduced from reference 15, copyright American Chemical Society)

The antibacterial properties of the finished fabrics were evaluated with Gram-positive and Gram-negative bacteria, fungus, yeasts, and viruses following AATCC standard test method 100. These microorganisms represent a whole spectrum of pathogens that healthcare providers are encountering every day. Based on characteristics of medical protection requirements, contact time of microorganisms on surfaces of fabrics was chosen at two minutes, which was the shortest interval when a microbiological test can be managed properly. Two commonly used fabrics, pure cotton and polyester/cotton sheets, were treated by finishing solutions containing 2% and 6% of dimethylol dimethylhydantoin (DMDMH), respectively, and bleached subsequently in a diluted chlorine solution. The results, listed in Table 1, are reported in log reductions of microorganisms, with one log reduction referring to 90% kill and three log reduction meaning 99.9% kill. Comparing to other antimicrobial textiles, the new biocidal fabrics exhibited superior properties as textile materials for medical workers and patients, owing to their rapid and effective inactivation of a broad range of microorganisms. In addition, the outstanding biocidal properties of the fabrics are durable and regenerable by chlorine bleaching, a process commonly used in commercial laundering of institutional textiles. The antimicrobial properties of the fabrics could be recharged after repeated laundering by the bleaching. Apparently, active chlorine in halamines could be affected by laundering detergents. Thus, after each laundry the fabrics are recommended be bleached to refresh the lost antimicrobial functions. Chlorine bleaching is a required process for used medical textiles, and using it in medical textiles is compatible with the existing operation. More recently, durable and regenerable

antimicrobial fabrics that can survive more than 50 machine washes without recharging have been developed by using the same chemistry.

Rechargeable biocidal finishing of textiles

N-halamine structures have been incorporated into cellulose-containing and nylon fabrics by a conventional finishing method in the presence of formaldehyde[16-19]. Recently, a hydantoin-containing monomer, 3-allyl- 5,5-dimethylhydantoin (ADMH, as shown in Fig. 3) was prepared to incorporate the same hydantoin rings into textiles[16-17]. Due to the allyl structure, ADMH forms its own homopolymer with difficulty, making it a good choice in grafting polymerisation, where the formation of homopolymers, which could consume as much as 80% of the monomers added, should be minimised [16-19]. By using radical initiators such benzoyl peroxide (BPO) and potassium persulphate (PPS), macroradicals could be generated on most synthetic and natural fibres. The macroradicals can then undergo radical addition reactions with ADMH. As a result, ADMH could be grafted onto cotton, cotton/polyester, nylon, polypropylene, and even high performance fabrics such as Nomex and Kevlar.

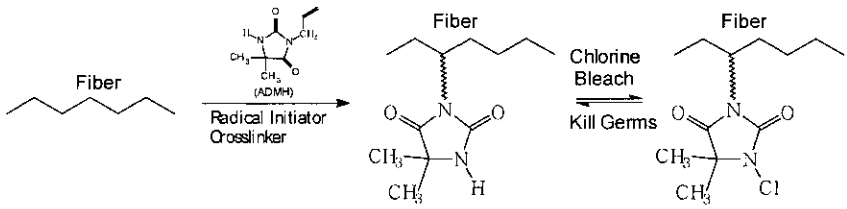

Figure 3. Controlled radical grafting reaction on fibres [19]

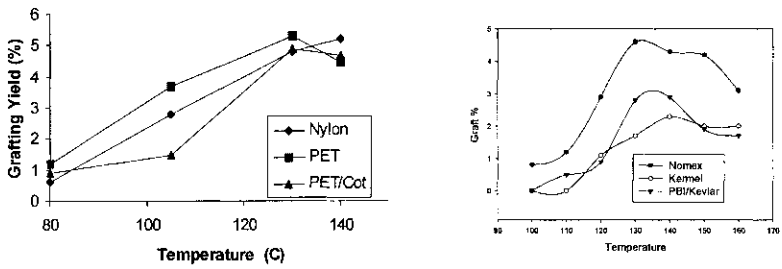

Figure 4.[18-19] Grafting add-ons on Nylon, PET, and PET/Cotton (a) and Nomex, Kermel, and PBI/Kevlar (b). (a) ADMH 4%, TATAT 1.5%, softener 1.5%, and BPO 0.2% at 100% wet pick-up and dried at 50 C for 5 minutes, then cured for 5 minutes; (b) ADMH 3 %, PEG-DIA 2 %, softener 1.5%, and initiator 0.5%. 100% wet pick-up, dried at 50 0C for 5 min., cured at varied temperatures for 5 min.

Most of the radical grafting reactions also need triallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione (TATAT) or poly(ethylene glycol) diacrylates (PEG-DIA) to increase grafting yields[16]. These are polyallyl or polyvinyl compounds, which can introduce crosslinking effect to the fabrics. The overall grafting reaction is controlled by carefully managing a

combination of radical initiation on polymers over monomers, addition of macroradicals to monomers, and crosslinking effects from the additives. Fig 4 (a) and (b) show grafting add-on of monomers under different temperature on several fabrics.

ADMH grafted fabrics could provide similar halamine structures to the grafted fabrics, and result in desired antimicrobial functions (Tables 2 and 3). The functions

Table 2. Antimicrobial properties of nylon, polyester and polyester/cotton[18]

Fabric	Add-on %	Percentage Reduction of *E. Coli* at different Contact Time (min)			
		5	10	20	30
Nylon	4.8	99.9	99.999	99.9999	99.9999
Polyester	5.3	No kill	90	99.9	99.999
Polyester/cotton	4.9	99.99	99.999	99.999	99.999

* AATCC test method 100. *E. Coli* concentration: 10^5 CFU /mL

Table 3. Antimicrobial properties of Nomex, Kermel, and PBI/Kevlar[19]

Fabric	Add-on %	Percentage Reduction of *E. Coli* at different Contact Time (min)			
		10	30	60	120
Nomex	4.6	UD	99.9	99.9999	99.9999
Kermel	2.3	UD	90	99.9	99.9
PBI/Kevlar	2.8	UD	UD	99.9	99.9

* AATCC test method 100. *E. Coli* concentration: 10^6 CFU /mL

Table 4. Washing durability and rechargeability of grafted Nomex fabric [19]

Washing time	Mcl x 10^5 (Mol/g)	Bacterial Reduction of Nomex (%)	
		E. coli	*S. aureus*
0	1.22	99.9999	99.9999
5	1.20	99.9999	99.9999
15	0.63	99.9999	99.999
30	0.27	99.9	99.99
50	UD	90	90
50	1.14	99.9999	99.9999

can be recharged in chlorine bleaching. In fact, after 50 washes all fabrics could still regain their biocidal properties easily. Due to hydrophobicity of several polymers, the active halamine structures could not be washed off easily. Table 4 shows antimicrobial results of Nomex fabrics after repeated washing and recharge. The antimicrobial properties on the Nomex fabric survived fifteen times laundry with minimal reduction of

efficacy. After 50 washes, a chlorine recharge can almost completely restore the lost chlorine on the fabric.

CONCLUSIONS

Durable and rechargeable antimicrobial textiles could be prepared with hydantoin derivatives by using two novel chemical treatments. The antimicrobial textiles produced with these technologies are biocidal materials that can provide rapid kill to a broad spectrum of pathogens, and the biocidal functions can be repeatedly recharged by chlorine bleaching. The chlorine bleaching is a required process for disinfection of medical use textiles. Therefore, this rechargeable biocidal textiles can be employed as medical textiles such as uniforms, patient dresses, bedding sheets and linens.

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BARRIER TEXTILES BY WET FINISHING AND PLASMA TREATMENT

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ABSTRACT

Surgical gowns need to have a barrier between the infection source (microorganisms like bacteria and viruses of different size and geometry) and the healthy person as well as a good wearing comfort. In addition to micro structure of the polyester fabric, it is required to modify the surface of the fabric in order to have a pre-barrier effect which will not allow the adhesion of the particle loaded liquids on the fabric surface and at same time will retain very good air permeability. The acquisition of hydrophobic behaviour of the fabric surface will provide haemo-repellancy and the prevention of bacterial attachment.

The following methods have been used to achieve the stated goals:

1. Wet-finishing of the fabric with fluorocarbons and silicones
2. Modification of the fabric surface by low-pressure plasma treatment.

Thereby, the original textile-physical properties like soft handle and air permeability should not be severely affected. Furthermore, a certain degree of washing permanence of the hydrophobic treatment effect should be also be ensured.

INTRODUCTION

The wet-finishing with different fluorocarbon resins under the application of a wetting agent leads to the highest water contact angle (up to 147°) on the fabric. The surface properties are not affected after 10 times washing with water, indicating stable surface treatments. The treatment with silicone-based chemicals leads likewise to wash-stable surface modification with a negligible decrease in air permeability. However, in this case the water contact angle is somewhat lower (approx. 140°) but a very pleasant grasp of the fabric is achieved.

On contrary, plasma-based fluorination using hexafluoroethane ($C_2 F_6$), has also been shown to improve the water repellency to a comparable level (contact angle 140°-145°) whilst the bulk properties of the original fabric remains almost unaffected.

EXPERIMENTAL

Material

In order to carry out the experiment a commercial polyester microfilament fabric was used. The fabric was prepared by scouring with sodium hydroxide (2 g/l) and a non-ionic detergent (3 g/l) at a temperature of 80° C followed by intensive washing.

Hydrophobic treatment

To achieve the modified fabric surface having a pre-barrier effect the following methods of treatments were applied:

1. Wet finishing of the fabric with fluorocarbons and silicones
2. Modification of the fabric surface by low-pressure plasma treatment.

The wet finishing treatment to increase the barrier effect of the fabric was carried out under the application of finishing agents by means of a well-known padding method (Fig. 1). After a short immersion (2 min) in a bath of finishing chemicals the fabric was padded with 60 – 70% pick-up, dried at 100°C for 2 minutes and condensed at 160°C for 2 minutes to attain the maximum effectiveness of the treatments.

As finishing chemicals, acrylate based fluorocarbon and polymethyl hydrogen siloxane as well as a non-ionic detergent (supplied by Rotta GmbH, Mannheim, Germany) with different concentrations were used.

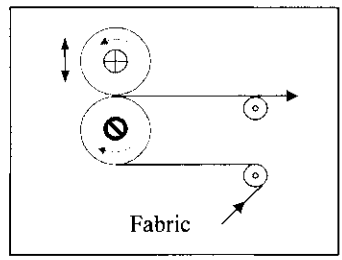


Figure 1. Padding mangle

Plasma treatments were carried out in a plasma equipment made by Buck plasma electronic, GmbH, Germany. The samples were treated with hexafluoroethane plasma and with its mixtures with H_2 in different ratios under different power, pressure and time conditions. The plasma was produced with a high frequency generator at the microwave frequency of 2.45 GHz.

Evaluation

Degree of hydrophobicity

To measure the extent of hydrophobic modification of the treated surfaces, the following two methods were applied:

1. Contact angle measurements: The measurements of sessile contact angle were carried out on treated substrates by means of a G 40 apparatus (Krüss, GmbH, Germany) with distilled water. The drop of water forming an angle may be considered as resting in equilibrium by balancing three forces involved (Fig. 2). Namely, the interfacial tension between liquid and vapour γ_{lv}, that between solid and vapour γ_{sv} and that between solid and liquid γ_{sl}, which are correlated by classical Young's equation:

$$\gamma_{sv} = \gamma_{sl} + \gamma_{lv} \cos\theta$$

where θ represents the surface contact angle or wetting angle. In these measurements, the typical standard variations were 1-2°.

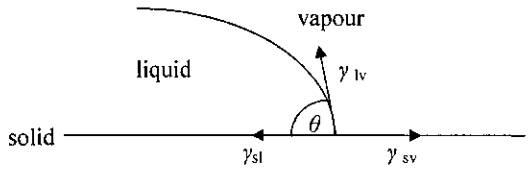
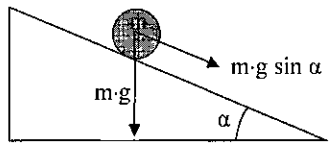


Figure 2. Schematic of three-phase contact

2. Sliding angle measurements: The angle of sliding of water droplets on the treated surfaces, i.e. at which angles the water droplets started to slide down were measured by the test schematically shown in Fig. 3. The effect of droplet size on the sliding angle was measured with six different volumes of droplets (10 µl, 20 µl, 30 µl, 40 µl, 50 µl and 100 µl). The standard variations of measurements in these cases were 2°.



α = Sliding angle
m·g = Gravitational force due to mass m

Figure 3. Schematic of sliding angle measurement

Air permeability

The change in air permeability of the treated fabrics was measured according to the norm EN ISO 9237 by using the air permeability measuring instrument 21443 (Frank, GmbH, Germany). Since the air permeability varies over the fabric width to a large extent (approx. 12 to 20 l/m^2s), it is given not in absolute value, but in proportional decrease in air permeability and calculated according to the equation below:

$$L\ (\%) = (L_b - L_a) \times 100 / L_b$$

where L_b and L_a denote the air permeability before and after the treatment respectively.

Washing permanence

The degree of stability of the treated surfaces was ascertained by subjecting the modified fabrics to a number of washing treatments (20 times) on laboratory scale according to DIN 45010, followed by contact angle measurements, which were carried out after 10 times and 20 times washing of the fabrics.

RESULTS AND DISCUSSION

In order to get the best results, the treatment with wet finishing chemicals and low pressure plasma were carried out with a variation of different parameters of application. The resulting degree of hydrophobic behaviour of the treated surfaces was determined by means of observing water droplets at a horizontal and an inclined surface in the form of contact and sliding angle measurements respectively. The best results obtained

thereby are summarized in Table 1. Since, in contrast to contact angle, the sliding angle depends on the size of droplet, it was measured in all these three cases with a constant volume of water droplet (10 µl).

Compared to silicone-based chemicals and C_2F_6 plasma treatments, fluorocarbon treated surfaces exhibit a better water repellency. Instead of spreading on the fabric surface, droplets of water assume roughly spherical shape and start to slide down at a small degree of inclination of the fabric. Silicone treated surfaces showed lower contact angles as well as corresponding higher sliding angles which can be attributed to higher surface energy of CH_3 groups of the finishing silicone polymer.

Table 1. Hydrophobicity of treated surfaces

Material	Contact angle (θ)	Sliding angle (α)
Fluorocarbon finished	147.0	11.5
Silicone finished	141.0	17.0
Plasma treated	141.3	19.1

On the other hand, the plasma treatments resulted in a hydrophobic surface that is not distinctively different and almost similar to that of silicone finished one.

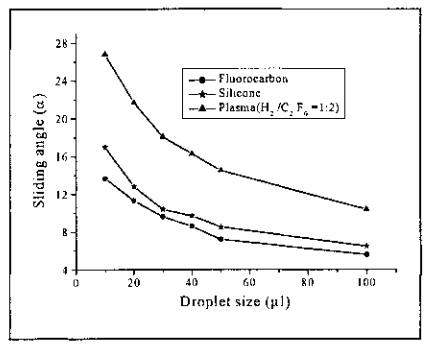


Figure 4. Sliding angle as a function of droplet size of water

The results obtained in both wet finishing and plasma treatment are plotted in Fig. 4, which expresses the variation of sliding angle depending on the size of water droplet. The sliding angle increases as the droplet size decreases. Bigger droplets have lower resistance against flow down, as it can be assumed to dominate the mass effect, $m \cdot g \cdot \sin\alpha$ (Fig. 3), over the surface tension effect causing to roll down the droplet on the fabric surface with a lower angle of inclination[1].

Air permeability

Apart from the desire for liquid-proof and for microorganisms impermeable medical textiles a pleasant wearing comfort at the same time is of very high demand. It is necessary, therefore, to exhibit a very good air permeability of the treated fabrics.

On contrary to fluorocarbon chemicals, the siloxane covers up the fabric surface down to the level of each single fibre[2] causing a homogeneous and closed structure of

the surface[3] which leads to a higher decrease in air permeability than that of fluorocarbon one (Fig. 5).

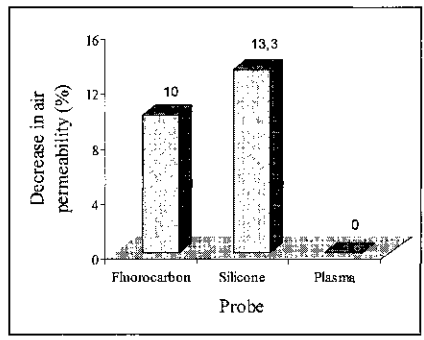


Figure 5. Different methods of modification with corresponding decrease in air permeability of the fabric.

Whereas, the wet finishing chemicals make the fabric hydrophobic leaving a thin polymer film on its surface, plasma treatment results in surface reactions, e.g. etching and deposition of the reaction products of the plasma[4]. There are many interactions which take place during plasma processing between the reactive plasma and fabric surfaces, but these interactions and reactions were not accompanied by any decrease in air permeability of the treated surfaces.

Washing permanence

It should be mentioned that reusable surgical gowns, the attempted application field for the polyester microfilament fabrics, have to be washed and sterilised repeatedly. Therefore, in addition to keep the fabric in its original state without affecting the initial textile physical properties, a certain degree of wash-stability of the hydrophobic treatment should also be given.

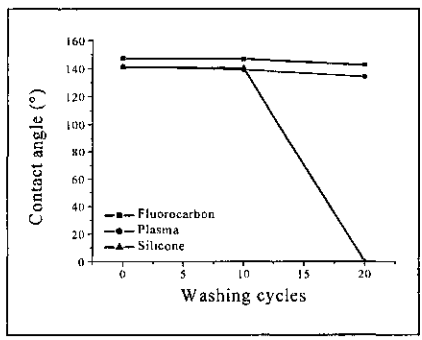


Figure 6. Effect of washing on the hydrophobicity of the treated fabrics

Experimental results have shown that after a series of washing treatments (20 times), the surface properties of fabrics modified with fluorocarbon chemicals are only moderately affected indicating considerably stable hydrophobic surfaces (Fig. 6). Washing the materials treated with C_2F_6 plasma reduces the hydrophobic character somewhat more than that of fluorocarbon indicating the removal of some of the non-polar groups from the surface, with contact angle decreased by 7°. But the surfaces treated with silicone chemicals are not stable at all. After 20 washes, a complete loss of hydrophobic behaviour is observed.

CONCLUSIONS

It is demonstrated that the treatment with fluorocarbon and silicone-based wet finishing as well as with C_2F_6 plasma improve the surface hydrophobicity of the PET microfilament fabric to a considerable level. Fluorocarbon chemicals are found to give the best results in respect of both water repellency and washing permanence with a negligible decrease in air permeability of the fabric. Compared to fluorocarbon the silicone treatment offers an excellent hand-feel of the fabric, but does not satisfy the demand of a wash-stable hydrophobic surface that is highly desired in the case of medical textiles. Plasma treatment, on the other hand, results in somewhat lower contact angle as well as higher sliding angle than that of fluorocarbon one. But it reveals to be a potential alternative method, considering economic and environmental aspects, since it is also found to produce considerable wash-permanent hydrophobic surfaces without affecting the bulk properties of the fabric.

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NOVEL APPROACH TO BREATHABLE NONWOVEN HYGIENIC PRODUCTS

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ABSTRACT

Cost contribution of nonwoven materials in hygiene products such as baby's nappies is about 10%. One of the main contributors to the cost in breathable nappies is the breathable sheet. The advantages of breathable nappies are in fact to reduce problems caused by babies skin not being able to get air i.e. nappy rash etc.

Moving from this idea of using nonwoven products instead of polyethylene film, which will not pass liquid outside but yet will give some form of breathability, was the main start point of this project. For this work various nonwoven products have been treated with water repellent chemicals and tested for water repellence as well as the tenacity and extensibility etc.

Keywords: Nonwoven, hygienic, baby nappy, breathable, water repellent, chemicals, tenacity, extensibility

INTRODUCTION

Cultural differences in diapering go back to ancient times. In most primitive societies, diapers were not worn at all and yet that is still true today in many warmer countries. In some societies, a diaper equivalent was used such as in some Native American tribes mothers packed grass under a diaper cover made of rabbit skin. By the late 1800s, infants in Europe and North America were wearing the progenitor of the modern diaper made of linen, cotton flannel or stocking net. In the 1940s, the rubber pant was introduced as the outer diaper cover and it was popular as it contained well and kept the outside of the diaper area dry. In the 1950s, the plastic pant replaced the rubber pant; diaper skin was "sealed" for the first time. The disposable diaper revolution began in the United States in 1961 when Pampers were first introduced. In Europe, tissue-based disposable diaper inserts were first available in Sweden in the late 1930s and followed by products using defibered wood pulp in the 1950s. In the mid 1980s a super absorbent core was added and since then there have been various refinements in diaper composition. Now disposable diapers are much more thinner, comfortable for babies and young children to wear and cause less skin irritation.

It should be borne in mind that the average child wears 4000 to 5000 diapers before being toilet trained. Those diapers are in contact with areas that are extremely thin, particularly genitals, so it is essential they are safe and non-irritating. The market for hygiene absorbent products was worth about $40 billion in 1999 and the disposables were about 15% of the total available market. On the other hand, diapers and training pants amounted to $19 billion or 84 billion units.

Today's absorbent products are made from a number of different raw materials and preformed component parts. The materials used vary from one product group to another and increasingly will also vary within any one-product group as different manufacturers seek alternative solutions to the complex problems involved in the production of absorbent products. But generally, diapers consist of three main zones as represented in figure 1.

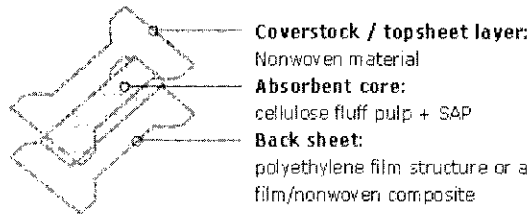

Figure 1. A baby diaper and its composition[1]

These products utilise cellulose fluff pulp combined with superabsorbent polymers (SAP), normally in powder form, to create the absorbent core that acts as the storage structure for fluids in the product. In some products, wetlaid cellulose tissue may be used as a containment wrap around the cellulose pulp/SAP core structure.

The coverstock or topsheet layer is a nonwoven material, which may be a spunlaid polypropylene web or a staple fibre thermally bonded nonwoven, and the web will normally be treated to give either hydrophobic or hydrophilic character depending on the application.

Modern products, particularly top range products, incorporate an acquisition/transport layer which may be formed from synthetic staple fibres thermally bonded in a nonwoven structure, or may be a structure formed from chemically and /or mechanically modified cellulose fibres.

To fulfil primary user requirements, the absorbent material must be contained and isolated from the baby's clothes or bedding when it is wet and this function is carried out by the back sheet, which may be a polyethylene film structure or a film/nonwoven composite, i.e. a so-called "textile backsheet" (TBS), which may also be breathable.

Elastic tapes and panels, hot melt adhesives and fastening tapes are also important components to produce a fully functional product.

Extensive research has been carried out on wet processing of nonwovens[1-9]. However, water repellency treatments of nonwovens have not received much attention. In this work water repellency of nonwoven fabrics were carried out with two different but both fluorocarbon containing water repellent agents. Later these nonwoven samples were analysed for their tenacity behaviour (both machine direction, MD and cross direction, CD), thickness, air and water repellency.

EXPERIMENTAL

Material and method

In this study four different weights of nonwoven fabrics made of 100% PP were used. These nonwovens were treated according to the pad-mangle method and with different concentrations of water repellent agents and dried at standard atmosphere conditions. Later, untreated and treated nonwoven fabrics were tested for their air permeability,water repellency and breaking strengths. Details of the nonwoven fabrics used in this work are given below.

Weight (g/m^2)	Type of Fibre	Production Method	Dimensions (cm^2)
20	100 % polypropylene	Dry Laid-thermobond	20x18
30	100 % polypropylene	Dry Laid-thermobond	20x20
40	100 % polypropylene	Dry Laid-thermobond	20x20
50	100 % polypropylene	Dry Laid-thermobond	20x20

In this study fluorocarbon based water repellent finishing agents have been used; details of the finishing agents used can be seen below:

Firm	Chemical structure	Ionic structure	Colour	Density 20^0C g/cm^3	pH
A	Fluorocarbon resin	cationic	Milky- white Emulsion	1.02	2-4
B	Fluorocarbon resin	Lightly cationic	Milky- white Emulsion	1.16	5-6

Padding and drying conditions used in this work are given below:

Firm	Model	Loading (K/cm)	Face Width/Diameter (mm)	Liquor Tanks Capacity Max.(ml)	Speed (m/min)	Pressure Max. (Bar/PSI)
ROACHES ENGINNERING LTD	1X2 BOWL Padder BVP Vertical	24	350/100	450-1000	0.60	5.5 / 80

Firm	Model	Temperature (^0C)	Face Width (mm)	Liquor Tanks Capacity Max.(ml)	Speed (m/min)
ERNST BENZ TEXTILMACHINE N	Dryer TKF/M350 3128.63	130	200	450-1000	2

Mechanical properties of nonwoven fabrics (both in MD and CD) were determined according to ASTM D 5034-95 standard [6] by using Instron 1011 instrument. All tests were carried out in standard atmosphere conditions (20 ± 2 C^0 and 65 ± 2 % RH) after 48 hours of equilibrium was reached. The breaking strength results of the samples were presented in Table 1, 2 and 3 and in Fig.3.1- 3.6. Five tests were carried out for each sample and the average reported.

RESULTS AND DISCUSSION

Water repellency test of the fabrics are carried out on Text Test FX 3300 equipment according to INDA IST 80.4 (01), Hydrostatic Pressure Test. The results of water repellency tests are given in Table 1.

Table 1. Water repellency results of nonwoven fabrics

	Untreated	Water repellent A			Water repellent B		
		20(g/L)	30(g/L)	40(g/L)	20(g/L)	30(g/L)	40(g/L)
Material weight (g/m^2)	mbar/min	mbar/min	mbar/min	mbar/min	mbar/min	mbar/min	mbar/min
20	2.5	7	6	7.5	7	7	7
30	0	9	7	7	10	10	9
40	1.5	12.5	10.5	9	13	11	13
50	0	9	9.5	9.5	10	9.5	10

The results show that some degree of water repellency has been demonstrated on the treated fabrics. Due to the composition and more open structure of the nonwoven fabrics it is very difficult to achieve even surfaces in nonwoven production and consequently it becomes very difficult to achieve good degree of water repellency. Eventhough finishing agents used were similar water repellent, the repellent B has shown little better effect than repellent A. Increasing the amount of finish used does not seem to increase the water repellency effect.

The other important aspect of this work was to measure the air permeability of the samples. These tests were carried out on WIRA 4111/98 Air Permeability Equipment using(INDA IST 70.1 (01)) ASTM D 737-95 standards and results are given in Table 2.

Table 2. Air permeability results of nonwoven fabrics

	Untreated	Water repellent A			Water repellent B		
	Air permeability	20(g/L)	30(g/L)	40(g/L)	20(g/L)	30(g/L)	40(g/L)
Material weight (g/m^2)	L/min	Air permeability L/min	Air permeability L/min	Air permeability L/min	Air permeability L/min	Air permeability L/min	Air permeability L/min
20	25	>25	>25	>25	>25	>25	>25
30	25	>25	>25	25	24.5	>25	>25
40	22	22.5	24.5	25	22.3	24	22
50	22.50	22.5	>25	22.8	22.5	23	22.5

Air permeability results have shown that due to the open structural composition of the nonwovens the air permeability of all the samples are quite high. Above 25 L/min could not be measured on the equipment. As the fabric weight increased the air permeability has reduced.

Table 3. Breaking strength of the nonwoven fabrics

	Untreated		Water repellent A						Water repellent B					
			20(g/L)		30(g/L)		40(g/L)		20(g/L)		30(g/L)		40(g/L)	
Material weight (g/m^2)	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD	MD	CD
	(N)	(N)	(N)	(N)	(N)	(N)	(N)	(N)	(N)	(N)	(N)	(N)	(N)	(N)
20	30	5	20	10	19	12	18	9	17	10	21	12	20	11
30	49	11	45	7	45	8	51	8	47	8	53	10	49	9
40	61	13	63	12	62	12	64	12	64	12	60	12	63	12
50	54	13	45	10	51	11	54	10	47	11	46	12	46	10

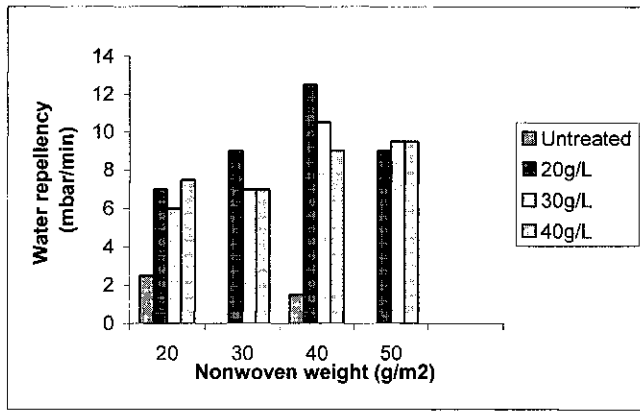

Figure 3.1. Water repellency of the nonwoven fabrics treated with water repellent A

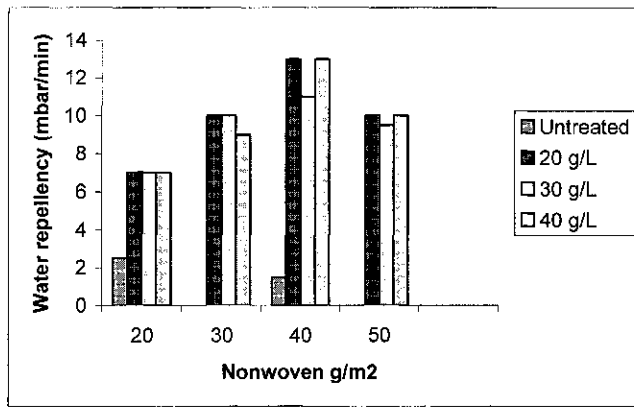

Figure 3.2. Water repellency of the nonwoven fabrics treated with water repellent B

Figures 3.1 and 3.2 show that water repellency increases with increasing fabric weight for the 20, 30 and up to 40 g/m^2 fabrics, but for the 50 g/m^2 fabric the effect is similar to that of 30 g/m^2 fabric. Results indicate that increase in the amount of water repellent does not show an increase in the effect. The use of 20 g/l water repellent gave the optimum result for each fabric weights.

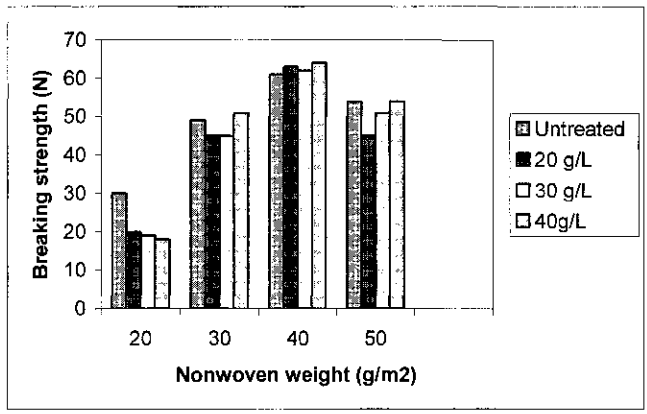

Figure 4.1. Breaking strength in MD of the nonwoven fabrics treated with water repellent A

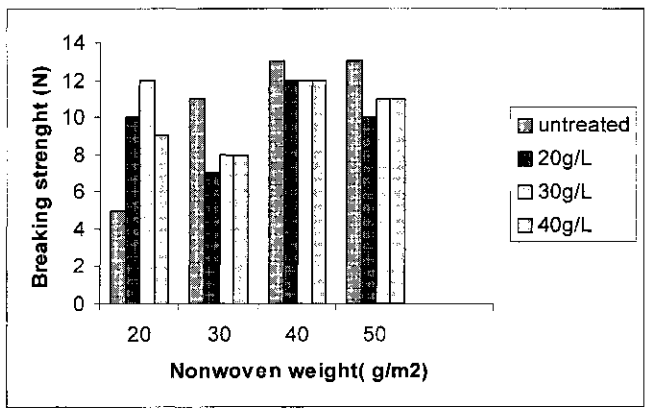

Figure 4.2. Breaking strength in CD of the nonwoven fabrics treated with water repellent A

It is generally agreed that nonwoven fabrics are stronger in machine direction than the cross direction. This is also seen in this work, and finishing applications did not change the tenacity much or it is very difficult to say otherwise. However, an increase is observed at 20 g/m^2 sample as a result of the finishing process.

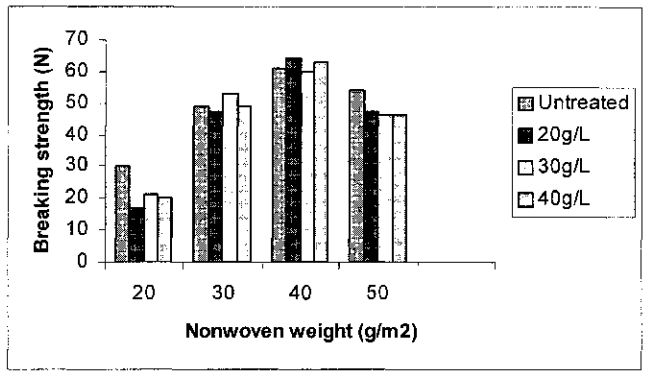

Figure 4.3. Breaking strength in MD of the nonwoven fabrics treated with water repellent B

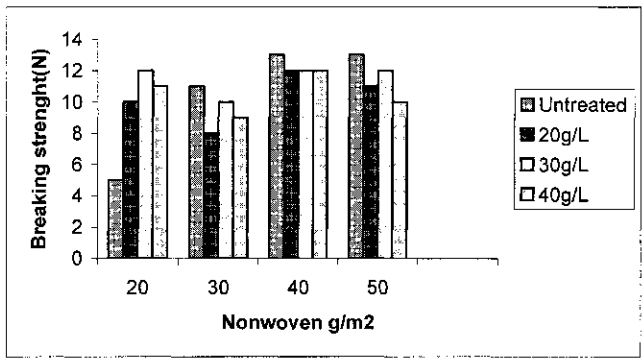

Figure 4.4. Breaking strength in CD of the nonwoven fabrics treated with water repellent B

The breaking strength of the water repellent treated nonwoven fabrics has indicated that up to 50 g/m^2 of weight of nonwovens the MD breaking strength increases as the weight of the fabric increases. However, CD breaking strength seems to display complicated behaviour (Fig. 3.2 and Fig. 3.4) but the higher strength has registered on the 40 g/m^2 of the nonwovens in both water repellency of 20g/ℓ and 40g/ℓ applications. In general, again, the highest MD breaking strength has been obtained on the 40 g/m^2 of the nonwovens in both water repellents (A and B) of 20g/ℓ and 40g/ℓ applications (Fig. 3.1 and Fig. 3.3).

CONCLUSIONS

To achieve even fibre distribution of nonwoven fabrics is very difficult. This is due to variations in various production techniques and the structural composition of the fabric. As a result it becomes very difficult to achieve reproducible results even under the same weights.

On the other hand, the overall results have shown that water repellency could be obtained even in lightweight nonwoven fabrics. But the water repellency effect could not be enough to be used in baby diapers with this low fabric weight and fabric type.

Water repellency increases with increase in weight of the fabric up to 40 g/m^2 with both the water repellents. The increasing amount of chemicals does not increase the water repellency of the fabrics. Water repellent treated fabrics do not influence the tenacity of the fabric significantly. Air permeability also not affected by water repellency treatments of the nonwoven fabrics. The best water repellency has been obtained from 20g/ℓ chemical used in 40 g/m^2 sample.

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