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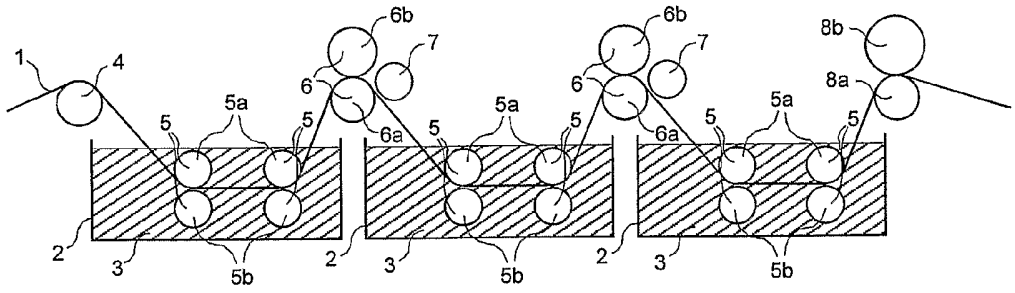
(54) **Title:** ELECTROSTATIC FILTER MEDIA AND A PROCESS FOR THE MANUFACTURE THEREOF



(57) **Abstract:** The present invention relates to an electrostatic filter medium (1) and a process for manufacturing an electrostatic filter (1). The electrostatic filter medium of the present invention is in the form of a non-woven web (1) containing one or more than one type of staple fibre, wherein the non-woven web is electrostatically charged and is compacted such that the electrostatic charge contributes to the filtration properties of the medium for a period of at least 100 days.

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ELECTROSTATIC FILTER MEDIA AND A PROCESS FOR THE MANUFACTURE THEREOF

FIELD AND BACKGROUND OF THE PRESENT INVENTION

The present invention relates to an electrostatic filter medium and a process for treating fabric that can be used as an electrostatic filter. Electrostatic filters are widely used for separating fine dust particles from a gas phase. For example, electrostatic filters were used during the First World War to protect soldiers against exposure to toxic arsenic fumes. Yet another example in which electrostatic filters are still being used is domestic and general air conditioning systems and in particular to remove dust particles including pollens from the indoor environment.

Conventional mechanical filters do not carry an electrostatic charge and are often made from coarse staple fibres having a diameter of 10μm or more. Mechanical filters are suitable for arresting coarse particles but are not as effective in removing fine dust particles having a diameter of 3 μm or less. The mechanical action of filter media generally has very little or no impact on the removal of particulates less than 3 μm in diameter due to the relatively small surface area and open structure of coarse fibre filters. However, mechanical filters made from relatively fine fibres of a few micrometers or less in diameter can be used to separate fine particles.

The use of small diameter fibres reduces the size of empty spaces or pores in a fibrous structure. The small fibre diameter also reduces the tensile strength of the filter media and the small pore size increases the pressure differential across the filter media. Electrostatically enhanced coarse fibre filter media can provide the capacity to filter relatively fine particles at a comparably low pressure drop. In addition, electrostatically enhanced filter media made of coarse fibre also have a comparably higher strength than filter media made from fine fibres. Coarse fibre filters can

also be formed into thick structures with high bulk, which provide an inherent ability to contain higher dust quantities.

For these reasons electrostatically enhanced filter media are generally seen as the preferred solution in gas filtration applications.

A disadvantage of electrostatically enhanced filters is that the electrostatic charge can dissipate over time and, therefore, become less affective as the filter medium ages. According to our experience the rate at which the electrostatic charge of conventional electrostatic filters deteriorates increases when the filter medium is exposed to high humidity, heat or ionising radiation. While some types of electrostatic filter media remain practically unaffected by dissipation of charge over time, they are still affected by the amount of stored charge that is consumed by captured dust particles settling on the fibre surface. The net effect from a reduced amount of stored charge combined with the build up of dust structures in the body of the medium can go both ways in terms of particle capture efficiency.

It is known that the retention of an electrostatic charge by a filter can be increased by compacting the filter medium during electrostatic charging. For example, US patent 4,588,537 describes a method of making an electrostatic filter that involves compacting a porous filter structure permanently or semi-permanently by "sandwiching" the filter medium between blocking foils and subsequently evacuating the air in between. The medium was compacted during a corona treatment and in theory can be applied to any dielectric filter material.

It is an object of the present invention to provide an alternative process for manufacturing an electrostatic filter medium having a lasting electrostatic charge.

SUMMARY OF THE INVENTION

The present invention is based on the realisation that a liquid can play a role in achieving compaction of the filter medium that can result in a lasting electrostatic charge.

According to the present invention there is provided a process for treating a fabric that can be used as an electrostatic filter medium, the process including the steps of:

a) compacting a non-woven web of fibres, or at least a portion thereof, by way of a mechanical means while the non-woven web or said portion is in contact with a liquid phase, and wherein the non-woven web contains one or more than one type of staple fibre;

b) drying the web of fibres; and

c) electrostatically charging the compacted web of fibres to enhance the capacity of the web to filter dust particles from a gas.

It will be appreciated that steps a) to c) may be carried out disjunctively or contiguously and that the steps can be carried out at one or more different locations.

It is preferred that before carrying out step b) the process include a step of washing the non-woven fibrous web to remove antistatic agents using a washing liquid.

It is even more preferred that the washing liquid be the liquid phase that is in contact with the non-woven web during step a).

An advantage provided by the preferred features mentioned above is that the web itself can be made from fibres on which waxes, oils, spin finishes and other contaminants are still present and that affective compaction of the fibres can be achieved while the fibres are wet from the washing liquid. Previously, it was common practice to first wash and dry staple fibres prior to assembling the fibres into a web which is then electrostatically charged. However, the preferred

features of the present invention mentioned above are based, at least in part, on the realisation that affective compaction of the web can be achieved in the presence of a liquid phase such as a washing liquid that is used to wash contaminants from a fully assembled web of fibres.

It will be appreciated by those skilled in the art of the present invention that the term "staple fibres" embraces any type of fibre other than continuous fibres or filaments. For example, the web may be made from spunbonded fibres, carded fibres, or air-laid fibres. In the instance when the fibres are extruded or carded fibres, the fibres usually contain antistatic contaminants such as waxes and spin finishes, whereas continuous fibres or filaments are more likely to be spunbonded or meltblown in a finished form that will not have external antistatic agents and therefore, will not require washing.

It is preferred that the staple fibres in the web be any one or a combination of cellulosic fibres , keratin fibres, proteinaceous fibres and synthetic fibres including polymers such as, but by no means limited to polyolefins, polyesters, polycarbonates, polyamides, polyurethanes, polyaramids, polyacrylonitriles, polyacrylics, polyvinyls, polyvinylidenes, polytetrafluoroethylene and respective polymer-copolymer-combinations and variations thereof. The structure of the synthetic fibres can be homopolymer, bi- or multi-component core-sheath, side-by-side, "segmented pie" or "islands-in-the-sea". It is also possible to use the "island"-polymer filaments which remain after the surrounding "sea"-polymer has been dissolved and washed off.

In the situation where the filter medium is made according to the present invention and contains polypropylene fibres only, we have found that the filtering capacity of the filter is at least twice that of an equivalent filter without an electrostatic charge. More particular, in terms of the quality factors Q and Q_x which are described below in more detail, the quality

factor Q of a polypropylene filter without an electrostatic charge is usually in the order of 7 kPa^{-1} (for a test face velocity of 0.15 m/s) and the Q_x value approximately equal to 20 nm. In contrast, a polypropylene filter electrostatically charged according the present invention has an enhanced capacity to retain the electrostatic charge which results in the filter medium having quality factors Q and Q_x of at least 14 kPa^{-1} (for a test face velocity of 0.15 m/s) and 40 nm respectively for a period of up to 12 months or more.

It is even more preferred that the washing liquid include any one or a combination of the following: an organic solvent, liquid carbon dioxide, water, or a detergent.

It is preferred that the step of washing the web involves the web travelling through one or more than one reservoir of the washing liquid.

In the situation where the step of washing the web involves the web travelling through two or more washing reservoirs, it is preferred that the step of compacting the web be to some extent carried out on the web after travelling through each washing reservoir.

It is preferred that the mechanical means used for carrying out step a) define an opening through which the web passes and the opening has a height that is less than the thickness of the web prior to compaction.

It is even more preferred that the mechanical means be a nip between one or more pairs of rollers and that step a) involves passing the web through the nip(s).

It is still even further preferred that in the situation where the step of washing the web involves the web travelling through two or more washing reservoirs, compaction of the web according to step a) be carried out by a mechanical means in the form of a pair of rollers between which the web travels.

It is preferred that the or each pair of rollers apply a compacting force ranging from 5 to 100 kN/m to the web.

It is even more preferred that the or each pair of rollers apply a compacting force to the web of approximately 10kN/m.

It is preferred that prior to step a) being carried out, the web of fibres undergoes an initial consolidation stage. For example, the initial consolidation stage may involve needle punching or spunlacing the web which may also be known as hydroentangling. The initial consolidation stage may also, for example, involve calendering the web which will flatten the web in a direction normal to the plane of the web. In the situation where the fibres include thermoplastic multi-component fibres, it is also possible that the initial consolidation stage may be carried out by thermal bonding. The packing density of the fabric after initial consolidation is preferably between 2% and 10%.

It is preferred that the web, once treated according to step a) have a packing density ranging from 5 to 30%.

It is even more preferred that the packing density of the web range from 10 to 20%.

The term "packing density" as used herein is a ratio of the density of a fabric to the density of the fibres contained within the fabric. Further details and an explanation of how to calculate the packing density of web is explained under the heading TRIALS in this specification.

It will be appreciated that the step of drying the web can be carried out using any suitable fan-forced or convective heating means.

Although it is possible that step c) may be carried out using any suitable means including needle punching or some form of rubbing, it is preferred that step c) be carried out by way of a corona discharge.

Although the fibres may be of any diameter, it is preferred that the fibres have a diameter of 9μm or more.

It is preferred that the mass per unit area of the non-woven web range from 100 to 1000 g/m^2.

It is even more preferred that the mass per unit area of the non-woven web range from 150 to 400 g/m^2.

It is preferred that the electrostatic filter medium have a filtration efficiency calculated according to a methylene blue particle filtration efficiency of 20% or more.

According to the present invention there is also provided an electrostatic filter medium made according to the process of the present invention described above. The electrostatic filter medium may also include any one or a combination of the preferred features described above.

According to the present invention there is provided an electrostatic filter medium including a non-woven web containing one or more than one type of staple fibre, wherein the non-woven web is electrostatically charged and is compacted such that the electrostatic charge contributes to the filtration properties of the medium for a period of at least 100 days.

In the context of the filter medium of the present invention, the term "electrostatic charge" refers to situations where the electrostatic charge has been induced or created by means other than incidental means such as charge created by drying or handling of the filter medium.

It is even more preferred that the electrostatic charge contributes to the filtration properties for a period of at least 365 days, or even more preferably for 2 years, 3 years or more.

It is preferred that any one or more of the following properties of the filter medium be greater or superior than a filter medium of the same makeup and at substantially the same base weight (g/m^2) without wet compaction: filtration efficiency(%), quality factor Q (kPa^{-1}) or quality factor Q_x(nm).

It is preferred that the filtration efficiency be at least 20% using a Methylene Blue Filter Test Instrument which is substantially based on the design specification of Australian Standard AS 1324.2-1996.

In the situation where the base weight of the filter ranges from 200 to 300 g/m^2 and a packing density greater than 5%, the filter has any one or a combination of the following properties using the Methylene Blue Filter Test Instrument:

- it is preferred that the filtration efficiency be at least 30% for a period at least 365 days;
- it is preferred that the quality factor Q be at least 14kPa^{-1} for a period of at least 365 days;
- it is preferred that the quality factor Q_x be at least 40nm for a period of at least 365 days.

In the situation where the base weight of the filter ranges from 200 to 300 g/m^2 and a packing density greater than 10%, the filter has any one or a combination of the following properties using the Methylene Blue Filter Test Instrument:

- it is preferred that the filtration efficiency be at least 40% for a period at least 4 days;
- it is preferred that the quality factor Q be at least 10kPa^{-1} for a period of at least 4 days;
- it is preferred that the quality factor Q_x be at least 28nm for a period of at least 4 days.

In the situation where the base weight of the filter ranges from 300 to 400 g/m^2, has a packing density greater than 10%, and has a hydrophobic spin finish:

- it is preferred that the filtration efficiency be at least 55% for a period at least 4 days;
- it is preferred that the quality factor Q be at least 10kPa^{-1} for a period of at least 4 days;
- it is preferred that the quality factor Q_x be at least 28nm for a period of at least 4 days.

In the situation where the base weight of the filter ranges from 300 to 400 g/m^2, has a packing density greater than 10%, and has a hydrophilic spin finish:

- it is preferred that the filtration efficiency be at least 55% for a period at least 20 days, and even more preferably at least 70%;

- it is preferred that the quality factor Q be at least 14kPa^{-1} for a period of at least 20 days;
- it is preferred that the quality factor Q_x be at least 40nm for a period of at least 20 days.

In the situation where the base weight of the filter ranges from 300 to 400 g/m^2, has a packing density greater than 10%, and has a hydrophilic spin finish:

- it is preferred that the filtration efficiency be at least 80% for dust loading of up to 8 g/m^2 for a period at least 128 days;
- it is preferred that the quality factor Q be at least 10kPa^{-1} for a dust loading of up to 8 g/m^2 for a period at least 128 days;
- it is preferred that the quality factor Q_x be at least 28nm for a dust loading of up to 8 g/m^2 for a period at least 128 days.

The performance criteria mentioned in the 5 paragraphs immediately above are based on the web comprising 100 percent polypropylene fibre. In addition, those skilled in the art will appreciate that hydrophobic and hydrophilic spin finishes of most common polymeric fibres are likely to need to be at least partially removed to enable successful electrostatic charging of the web and to prevent accelerated decay of the electrostatic charge.

According to the present invention there is also provided a plant for treating a fabric that is suitable for manufacturing an electrostatic filter medium, the plant including:

mechanical compacting means in which a non-woven web of fibres, or at least a portion thereof, can be compacted while the non-woven web or said portion thereof is in contact with a liquid, and wherein the non-woven web contains one or more than one type of staple fibres;

a drying stage in which the liquid can be dried from the compacted non-woven web; and

means for electrostatically charging the compacted fibres to enhance the capacity of the web to filter dust particles from a gas.

Although it is possible that the mechanical compacting means can be achieved using any suitable format, it is preferred that the compacting means be in the form of one or more than one nip formed between a pair of rollers.

It is preferred that the plant further include a washing stage in which a washing liquid can remove antistatic agents, such as but by no means limited to, waxes, oils and spin finishes from the exterior of the fibres of the web.

It is even more preferred that the washing liquid be the liquid in contact to the non-woven web during the compacting stage.

It is preferred that the washing stage include one or more than one vessel through which the web can travel.

It is even more preferred that each vessel include one or more rollers that define a path submerged in the washing liquid along which the web can travel.

It is preferred that the washing stage include two or more than two vessels and that the mechanical compacting means include a series of substages each located after the vessels and are adapted for compacting the web to some extent after each washing vessel.

It is preferred that the or each nip provide a compression force ranging from 5 to 100 kN/m to the web as it passes through the compacting stage.

It is preferred that the plant include an initial consolidation stage for improving the web strength prior to compacting while the web is in contact with a liquid phase.

The initial consolidation stage may, for example, be carried out by way of needle punching, spunlacing or thermal bonding. It is preferred that the web has a packing density between 2% and 10% after the initial consolidation stage.

The plant of the present invention may also include any one or a combination of the preferred features of the process described above.

BRIEF DESCRIPTION OF DRAWINGS

A preferred embodiment of the present invention will now be described with reference to the accompanying figures, of which:

Figure 1 is a block diagram showing the steps of a process;

Figure 2 is a side alleviation of a combined washing and compacting stage comprising 3 substages that are utilised by the process; and

Figures 3 to 5 illustrate alternative configurations of combined washing and compacting substages for compacting a web.

Figures 6a and 6b are schematic drawings of a Laser Opacity Meter that can be used for testing the filtering capacity of the filter medium carrying out a methylene blue filter test.

Figure 7 through to Figure 14 illustrate a series of results of trials carried out on sample electrostatic filter media made according to the preferred embodiment, namely examples 3 to 7 and comparative filter media, namely examples 1, 2 and C1.

Figure 7 through to Figure 26 illustrate a series of results of trials carried out on sample electrostatic filter media made according to the preferred embodiment, namely examples 3 to 15 and comparative filter media, namely examples 1, 2, C1, C2 and C3.

Figure 27 is a series of photographs showing side views of compacted examples 11, 12 and the corresponding uncompacted precursor C3. A true scale of 0.5mm per division is shown on the right side of photograph.

DETAILED DESCRIPTION

As can be seen in Figure 1, the preferred embodiment is both a plant and process for treating a non-

woven web of fibres to form an electrostatic filter medium having an enhanced filtering capacity. As described above, the non-woven web preferably contains one or more than one type of staple fibres. The plant includes an initial consolidation stage, combined washing and compacting stages, a drying stage and an electrostatic charging stage.

As will be explained in further detail below, the preferred embodiment of the present invention differs from technology presently available in many respects including, but by no means limited to, a combined washing and compacting stage.

The initial consolidation stage involves consolidating the web of non-woven fibres to a packing density, which is preferably as high as 5%. Typically, the initial consolidation stage may involve the use of conventional machinery to carry out needle punching, spunlacing or calendering so as to flatten the web in a direction normal to the plan of the web. In the situation where the fibres include thermoplastic multi-component fibres, it is also possible that the initial consolidation stage may be carried out by thermal bonding between the fibres. The primary purpose of the initial consolidation stage is to consolidate the web and attain sufficient tensile strength that will avoid the web breaking, stretching or drafting during subsequent processing of the web.

The term "electrostatic depleting contaminants" as used herein embraces antistatic agents that may cause one or a combination of: (i) a reduction in the extent to which an electrostatic charge can initially be applied to a web; and (ii) reduces the capacity of the fabric to retain an electrostatic charge once applied.

A side view of three combined washing and compacting stages is shown in Figure 2. Each sub-stage includes a vessel 2 containing a washing liquid 3, at least one guide roller for guiding web into the vessel and a pair of submerged stainless steel rollers 5. As can be

seen, web 1 is fed into the first sub-stage via a driven guide roller 4. Two pairs of stainless steel rollers 5 are submerged in the washing liquid and define a nip between which the web travels. The rollers 5 are intended to remove air bubbles from the web 1 and thereby increase wetting of the fabric with the washing liquid. Each pair of rollers 5 comprises a driven top roller 5a and a spring loaded bottom roller 5b. Although not shown in the drawings, a purge stream may be continuously or periodically discharged from the vessel 2 and a fresh make up stream of washing liquid fed into each vessel 2. The purpose of this procedure is to ensure that the concentration of electrostatic depleting contaminants in the washing liquid is kept at an appropriate level. Moreover, to ensure that the web is washed with fresh washing liquid immediately prior to leaving the vessels, the washing liquid may be conveyed from one vessel 2 to another in a direction opposite to the direction of motion of the web between the vessels 2. That is, fresh washing liquid may be supplied to the last vessel 2 as seen in the direction of motion of the web and discharged from the first vessel 2 entered by the web.

The web leaving the first and second sub-stages pass through the nip of a rubber-coated pair of pressure rollers 6a and 6b. Roller 6b is an idling roller, whereas roller 6a is a driven roller. The rollers 6a and 6b express liquid from the web and apply a compacting force to the web. Preferably, the compacting force is in the range of 5 to 15 kN/m. The compacting force is generated by rollers 6a and 6b being moveable relative to each other in a direction perpendicular to the direction of travel of the web by hydraulic actuators. In the event that the additional compacting force is required, it may be necessary to replace the rubber coated rollers 6a and 6b with stainless steel rollers.

An additional third roller, roller 7 facilitates the detachment of the web from high pressure roller 6b and

guides the web towards the next set of rollers 5 submerged in the washing liquid in the following substage.

The third substage is equipped with a large roller 8b located above the driven roller 8a, which makes roller 7 obsolete as a result.

Approximately 0.75 metres of the web is submerged in the washing liquid in each vessel. It will be appreciated that the removal of the antistatic contaminants from the web is a function of the speed at which the web is passed through the washing vessels and that length of the web submerged in each vessel. Trials can be carried out to ensure that the web is submerged in the washing liquid for a sufficiently long period to remove the contaminants.

The washing liquid may be any suitable liquid including, but by no means limited to organic solvents, liquid carbon dioxide, water or a detergent. In some situations where the contaminant is a silicone-based hydrophobic spin finish, the web may require washing with a non-polar solvent such as dichloromethane.

By passing the wet fabric through pairs of high pressure squeeze rollers 6, the pressure from the rollers on the wet fabric renders the physical structure more compact. The level of compaction is significantly higher when the fabric is wet as compared to when it is dry. Moreover, we have realised that by increasing the packing density, the stability of an electrostatic charge can be increased.

A substantial portion of the liquid picked up by the fabric during washing is expressed from the web as it passes through the last pair of squeeze rollers 8a and 8b. The remaining liquid is dried off using any suitable air blow and/or heating means.

Finally, the dried fabric is then electrostatically charged by exposing the web to ions from a DC corona breakdown. It should be possible to use various different breakdown cell designs for this purpose but it may be necessary to treat the web in several passes

or in several stages to obtain the desired electrostatic charging. For example, the breakdown cell may include a pair of electrodes one of which is a stainless steel wire and the other a stainless steel plate with rounded edges. The polarity of the voltage applied to the wire electrode can then be used to determine the polarity of the ions generated in the breakdown. Positive, negative as well as combinations of positive and negative polarity can be suited to electrostatically charge the web.

Although the preferred embodiment described above involves combined washing and compacting stages, it will be appreciated that these stages may be configured separately and that the liquid contacting the web during compaction may be a liquid phase other than the washing liquid.

The preferred embodiment is more effective in treating a web having a weight basis of 150 g/m^2 or more. In the event that the weight of the web is less, we recommend treating several webs one on top of the other.

A person skilled in the art of the present invention will appreciate that many modifications and variations may be made to the present invention without departing from the spirit and scope of the present invention.

For example, Figure 3 illustrates an alternative washing vessel configuration including an additional pair of the rollers 5 and top rollers 9 that in essence increases the length of the web in the washing vessel. The configuration shown in figure 3 is therefore suited to situations where the web requires a greater period of contact with the washing liquid in order to remove contaminants.

Figure 4 illustrates an alternative washing vessel that is preferred when the contaminants settle to the bottom of the vessel. As can be seen, a series of the rollers 10 and 11 define a path for the web whereby the web is initially directed toward the base of the washing vessel were the concentration of heavy contaminants may be

high and then progressively upward into washing liquid having a lower concentration of the contaminants.

The embodiment shown in figure 4 also includes a baffle plate 13 which separates the washing vessel into sections where the web moves downwardly and upwardly in the vessel. The advantage provided by this configuration is that when the contaminants tend to dwell at the surface of the liquid, the baffle 13 can reduce the potential for the contaminants contacting the web as it leaves the washing vessel if the web travels in direction opposite to the direction shown by the arrows in Figure 4.

The embodiment shown in Figure 5 includes two aprons 14 and 15 which guided the web through the washing vessel and absorbed stress imposed in its main and cross directions. An advantage provided by this embodiment is that the aprons 14 and 15 can be used to support low strength webs that may not have undergone the initial consolidation. Ideally, the aprons have an open scrim-type structure so as not to hinder penetration of the washing liquid through the apron to the web.

Filter Quality and Benchmarking

The quality of a filter medium was described by R.G. Dorman in a text by P.A.F. White, and S.E. Smith entitled HIGH -EFFICIENCY AIR FILTRATION , Butterworths (1964) by the following equation:

$$(1) \quad Q' = -100\, log(P) / \Delta p$$

where P denoted the penetration of the filter medium, which is equivalent to (100% - F) in terms of the filtration efficiency F, and Δp denoted the respective pressure drop. In the following discussion we will use a slightly different form of the same quantity, defined as

$$(2) \quad Q = - ln(P) / \Delta p \qquad [kPa^{-1}]$$

and which we refer to as the "quality factor Q". As other authors have done before, we will use the natural logarithm to base e = 2.71828... in our definition of Q.

This definition of Q does not allow the comparison of values that were determined from measurements conducted at different face velocities v_f, i.e. the velocity at which the gas flows through the filter. An increase of the face velocity usually reduces the filtration efficiency of the filter medium and increases the pressure drop at the same time. As a result, the numerator ($-ln(P)$) of equation (2) is decreased while the denominator (Δp) is increased, leading to an overall reduction of Q. The quality factor should however not change when the face velocity changes, because the quantity should characterise the properties of the medium only. In order to compensate for the influence of the face velocity, we derived a different type of quality factor that used a dimensionless version of Darcy's Law described by C.N. Davies in a text entitled "Air Filtration", Academic Press, London, NY (1973) to account for the resistance of the filter medium as the face velocity was changed. Darcy's Law takes on the form of

$$(3)\ (\Delta p\ A\ r^2) / (\eta\ q\ h) = f(c) \qquad \text{(unit: [1])}$$

with A denoting the filter area, r the mean fibre radius, η the dynamic gas viscosity, q the rate of airflow, h the thickness of the filter medium and f(c) a dimensionless function of the packing density c. If the equation is regrouped to show parameters of the test environment on the left side and fabric properties of the filter medium on the right, we obtain:

$$(4)\ (\Delta p\ A) / (\eta\ q) = \{f(c)\ h\} / r^2 \qquad \text{(unit: } [m^{-1}]\text{)}$$

This equation can be rewritten to include the face velocity $v_f = q/A$:

$$(5)\ \Delta p / (\eta\ v_f) = \{f(c)\ h\} / r^2 \qquad \text{(unit: } [m^{-1}]\text{)}$$

It is an interesting property of this relationship that design parameters of a filter medium determine the right side of the equation but have no bearing on the left side. Definition (2) for quality factor Q has the same characteristics in that the equation contains only parameters of the test environment, but none that are specific of the filter design. Following this line of argument, we define a face velocity compensated form of the quality factor as follows:

$$(6)\ Q_x := \{-ln(P)\ v_f\ \eta\} / \Delta p \qquad \text{(unit: } [m]\text{)}$$

Using $\eta = 1.82 \cdot 10^{-5}$ Ns/m^2 as the dynamic gas velocity for air, we can now calculate and compare quality factors Q_x for filter media that were tested at different face velocities.

METHODOLOGY AND TEST METHODS

The present invention will now be described with reference to a series of trials that have been included for illustrative purposes only. It is intended that the trials demonstrate the effectiveness of the electrostatic filter media that have been made in accordance with the preferred embodiment described above. It will be appreciated that the present invention is not to be limited to the particular operating parameters and make up of the filter media described in the trials.

Methylene Blue Particle Filtration Efficiency Test

The performance of a filter can be assessed by monitoring the pressure drop and filtration efficiency of a filter medium when it is loaded with a methylene blue dust.

By calculating the quality factors from the measured data according to equations (2) and (6) set out above it is further possible to quantify the affect that

the stored electrostatic charge had on the overall performance of the filter medium.

The results set out below under the heading TRIALS have been obtained through the use of a Methylene Blue Filter Test Instrument (MBFTI) which is substantially based on the design specifications of Australian Standard AS 1324.2-1996 and involved the use of an Opacity Meter.

Figures 6a and 6b illustrate the Opacity Meter in two different operative orientations, namely an orientation in which methylene blue dust is loaded onto a membrane (i.e. Figure 6a) and another orientation in which the transmission of the loaded membrane is assessed (i.e. Figure 6b).

Although not shown in the drawings, a sample of filter medium being tested is exposed to a stream of particles in a conduit and two Opacity Meters are flow connected to the conduit, one located on either side of the filter medium being tested i.e., upstream and downstream of the filter medium. This allows the capacity of the filter medium to be assessed through use of the Opacity Meter.

The Opacity Meters include a light source in the form of a diode-laser module having a 3 milliwatt optical power capacity and produce light with a 670 nm wavelength. The module also contained an integrated internal feedback system for the purpose of stabilizing the output intensity of the laser beam. A combination of lenses provided for an adjustable beam geometry within a focus range of 35 mm to infinity. With the focus set to infinity, the beam assumed a rectangular shape of 4 mm x 2 mm in size. The beam diameter in the focus was < 50 µm and the beam divergence < 0.5 mrad. The choice of a laser source over a tungsten-halogen lamp, as required by the standard, provided significant advantages with regard to the delivery of high intensities to the target and in terms of limiting the generation of heat. The standard required a negligible response outside the wavelength range of 400 to 700 nm, which had been implemented in the standard by a limited

spectral response of the receiver. Lasers fulfil this requirement naturally via the spectral discrimination of the emitted laser light by the gain medium. The standard required further a maximum spectral response in the wavelength range of 500 to 600 nm. The light emitted by the laser module consisted of a few narrow emission lines in a wavelength range of 660 to 680 nm, which were located close to the main absorption band of methylene blue in aqueous solution, with its peak at 660 nm. The optical transmission of the methylene blue stained filter membrane was therefore very sensitive to the amount of dust deposited. It should be noted, that the absorption spectrum of dry methylene blue was different from that of the methylene blue solution, as was apparent from its slight purplish colour, and produced consequently a slightly different spectral response.

During loading, the test dust from the respective sampling tube enters the Opacity Meter via a 3-way cock 16 as shown in Figure 6a where it is directed to filter membrane 17 in holder 18. The dust particles settled on top and within the filter membrane. The particle-free air left the Opacity Meter via the outlet 19 of T-section 20 below the membrane holder 18.

During the optical transmission measurement, a beam 21 of the laser module 22 propagates along the straight path of the 3-way cock 16 and hit the centre of filter membrane 17 as shown in Figure 6b. Part of the light was absorbed by the methylene blue deposits 24 that have been accumulated on the membrane during sampling and °°the rest emerged as scattered light on the other side of the membrane. A given percentage of the scattered light was detected by photodetector 25 from where the signal was amplified and transmitted via an electrical lead 26 to a display or a processing unit.

The Opacity Meter can be switched easily from the sampling mode to the opacity measurement mode, and vice versa, via the 3-way cock 16. This was done either manually or via an actuator. The 3-way cock 16 also

protected the laser module from contamination with dust. The photodetector was protected from methylene blue contamination by the filter membrane.

The adopted testing procedure had a few more deviations from the Australian Standard: The filter membranes were not steamed after loading since the dust deposited on the membrane was sufficiently uniform. As a result, it was possible to re-use the same membrane for typically 5 consecutive cycles of dust sampling followed by an optical transmission measurement. A benefit of re-using the filter membranes was a reduced statistical error for the calculated non-linear statistical averages of the filtration efficiency, in comparison to the use of different membranes for each sampling.

TRIALS

Set below is a discussion on a series of trials.

In addition to assessing pressure drop and quality factors according to equations (2) and (6) and the filtration efficiency using the MBFTI, the physical properties of the filter medium including weight, thickness and packing density were also calculated.

The packing density of the filter medium was obtained by cutting circular discs of the filter medium with a diameter of 109 mm and measuring the thickness. The thickness was measured by placing one of the discs between a flat metal base and a 2.5 mm thick glass plate placed on the top of the disc. A thickness reading was taken and the fabric density calculated. A corresponding packing density was calculated by dividing the fabric density by the average density of the fibres contained in the material of the filter medium. In other words, the packing density increases as the voids between the fibres in the filter medium decrease in size.

As will be shown with reference to the test results below, the ability for a filter medium to retain an electrostatic charge is to a large extent dependent on the packing density of the filter medium.

Examples 1 - 4

Examples 1 to 4 involve the use of electrostatic filter media with packing densities ranging from 3.7 % to 5.8 % and comprising solvent cleaned polypropylene fibres. All samples were made from 3 denier polypropylene fibres of 55 mm length containing hydrophobic, silicone-based spin finish. The fibres were carded on a woollen card and subsequently needle punched (Laboratory fibre locker, serial P8701, available from James Hunter Machine Co., North Adams, Massachusetts, USA). Examples 1, 3 and 4 were needle punched at 50 insertions per square centimetre (ins./cm^2) and Example 2 at 250 ins./cm^2. Example 3 was also treated, by being passed through two substages of the combined washing and compacting substages shown in Figure 2. The washing vessels were filled with water at 50 °C temperature containing 0.1 % of non-ionic detergent (TN450). Detergent residues were removed in a separate process, by washing the web in tap water and leaving them to dry at room temperature. Example 4 was treated as per Example 3, but was passed through the combined washing and compacting stages twice.

All four Examples were subsequently cleaned by immersing in 1,1,1-trichloroethane (TCE) in a flat tray and were left to dry in a fume cupboard. The examples were subsequently electrostatically charged by a positive polarity DC corona breakdown in 6 passes at 1.3 m/min transport speed. The ion-generating wire electrode had a diameter of 0.32 mm and was located at a distance of 45 mm to a plate electrode, which extended on both sides of the wire in perpendicular direction over a distance of 0.1 m. The voltage across the electrodes was +32 kV and the examples were in contact with the plate electrode for the whole time of the treatment.

The sample mass per unit area of the test media varied between 195 and 252 g/m^2 as shown in Table 1 below. Fabric and packing densities of each example are also listed in the legend of Figure 7. It was expected that

the media of Examples 2 and 4 would have a lower mass per unit area, due to a more rigorous treatment by the needle punching or the squeeze rollers, respectively. The additional treatment which Example 4 received during the second pass did not only reduce the mass per unit area of the fabric in comparison to that of Example 3, but had also an adverse effect on its packing density. This result suggests that an indiscriminate application of additional compacting steps does not necessarily increase the packing density of the fabric.

The filtration efficiency of the examples was measured at different points in time over a number of days using fine methylene blue dust particles in accordance with the MBFTI methodology is plotted in Figure 7.

Changes in filtration efficiency are often accompanied by pressure drop variations. The measured pressure drop changes for Examples 1-4 were plotted in Figure 8. The differences from the lowest to the highest pressure drop reading were found to be larger for the media with high filtration efficiencies, which came as a result of the dust collected by the medium during the test. The collected dust particles did modify the structure of the web and increased its resistance to airflow. From the filtration efficiency and pressure drop measurements of Figures 7 and 8, values for the quality factors Q and Q_x could be calculated according to equations (2) and (6). The results have been plotted in Figures 9 and 10, respectively.

The results clearly demonstrate that the compacted filter media exhibited improved filter performances in terms of filtration efficiency and quality factor in line with an increase of packing density. It is noted furthermore that the quality factors of the compacted Examples 3 and 4 were relatively similar in magnitude, which may indicate that these media had reached a performance limit that was characteristic for this type of electrostatic filter at a given mass per unit area.

Table 1: Fabric properties and processing parameters of Examples 1-4.
Spin finish (Sf) options: I = insoluble / hydrophobic; S = soluble / hydrophilic.

Example	Mass per unit area [g/m^2]	Thick-ness [mm]	Packing Density [%]	Needle Punch [ins./cm^2]	Compact-ing	Sf	Cleaning Solvents
1	252	7.1	3.9	50	No	I	TCE
2	195	4.3	5.0	250	No	I	TCE
3	244	4.7	5.8	50	2 substages	I	TN450, TCE
4	201	4.0	5.5	50	2x 2 substages	I	TN450, TCE

Examples 5 - 7 and Comparative Example C1

The Examples 5 to 7 and C1 comprise filter media having a mass per unit area of more than 200 g/m^2 and comprising 3 denier polypropylene fibres with an external hydrophobic spin finish. The fibres were carded and subsequently needle punched at 125 ins./cm^2 from both sides.

Comparative Example C1 was not subjected to any further treatment.

In the case of examples 5 to 7, hydrophobic spin finish residues were removed by means of padding the medium in dichloromethane (DCM) in a flat tray. This step would be implemented in an industrial process by means of a washing stage such as that shown in Figure 2. The solvents were left to drain from the cleaned media for a few minutes, but further compaction was carried out while the medium was still damp in order to simulate the conditions of a continuous manufacturing process.

The manufacture of the Example 5 involved treating the medium twice through 3 compacting and washing

substages as shown in Figure 2. The washing vessels contained water at 60-65 °C temperature.

Example 6 was manufactured and treated in the same manner as Example 5 with the only exception that 0.1% of non-ionic detergent (BD40) had been added to the water of the first washing vessel of the 6-substage washing and compacting stages.

Examples 5 and 6 were then dried in a through-air bonding oven (Thermo Bond Oven, Serial No 6930/12/98, available from Gyson, Dandenong 3175, Australia) at 100°C.

Example 7 was manufactured from a different type of polypropylene fibre having an external hydrophilic spin finish. The spin finish was readily removed in warm water. The 3 denier fibres (Polyolefin Staple Fibre, type T-1001, available from Kolon Glotech, Inc., Kyunggi-do, Korea) had a similar diameter to those used previously for examples 1-6, but the fibres were longer. The original fibre length of 64 mm was well suited for processing on industrial scale equipment, but caused problems when used in conjunction with smaller scale processing equipment, as used in this instance for the manufacturing of the test samples. The problem was solved by guillotining the polypropylene fibres to a length of 38 mm. The shortened fibres were carded and subsequently needle punched at 125 ins./cm^2, in the same way as Examples 5 and 6. Example 7 was passed twice through the washing and compacting substages in Figure 2, wherein the washing stages contained water only. Example 7 was subsequently dried in the same manner as Examples 5 and 6.

The fabrics of Examples 5 to 7 and of Comparative Example C1 were electrostatically charged by a positive polarity DC corona breakdown in 6 passes at 1.3 m/min transport speed.

Physical properties of the examples are shown in Table 2: below. In addition, the thickness of the compacted fabrics was approximately half that of the uncompacted Comparative Example C1.

Table 2: Fabric properties and processing parameters of Examples 5-7 and Comparative Example C1.
Spin finish (Sf) options: I = insoluble / hydrophobic; S = soluble / hydrophilic

Example	Mass per unit area [g/m^2]	Thick-ness [mm]	Packing Density [%]	Needle Punch [ins./cm^2]	Com-pacting	Sf	Cleaning Solvents
5	266	2.2	13.2	2x 125	2x 3-substages	I	DCM, Water
6	238	2.1	12.6	2x 125	2x 3-substages	I	DCM, BD40
7	207	1.8	12.4	2x 125	2x 3-substages	S	Water
C1	270	4.1	7.2	2x 125	No	I	-

Filtration efficiencies of the examples according to MBFTI test is plotted in Figure 11.

The untreated Comparative Example C1 had clearly the poorest performance, followed by those of Examples 6 and 5. Examples 5 and 7 exhibited relatively similar filtration efficiencies, but Example 7 had a better overall performance due to a lower pressure drop (see Figure 12). The Comparative Example C1 had the lowest pressure drop, which was due to a much lower packing density and was not washed which is likely to have depleted its electrostatic charge. Example 7 had the best overall performance in terms of the quality factors Q (see Figure 13) and Q_x (see Figure 14), which indicated that the application of DCM to Examples 5 and 6 may have been insufficient to remove the hydrophobic spin finishes to optimal residue levels.

Examples 8 - 13 and Comparative Examples C2 - C3

Examples 8 to 13, C2 and C3 comprise filter media having a mass per unit area of approximately 400 g/m^2 and

comprising polypropylene fibres having external hydrophobic or hydrophilic spin finishes.

Hydrophobic spin finish

Examples 8, 9 and C2 were manufactured in accordance with the same sequence of steps used to manufacture Examples 5, 6 and C1 described above.

Example 10 was manufactured in accordance with the same sequence of steps as Example 9, except the medium was passed only once through the combined compacting and washing substages shown in Figure 2.

Hydrophilic spin finish

Comparative Example C3 was manufactured from guillotined polypropylene fibres having an external hydrophilic spin finish. The fibres were initially carded into a web of the required mass per unit area and needle punched at 125 ins./cm^2 from both sides. The web was then subjected to a corona discharge treatment at this point.

Examples 11 to 13 were manufactured in accordance with the method of manufacture of C3 described above, however, in the case of the Example 11, the medium was further treated in a total of 6 substages of washing and compacting in accordance with Example 7. Example 12 was treated in a total of 3-substages of washing and compacting. Example 13 was manufactured in accordance with Example 12, however, the first washing and compacting substage contained water with 0.1% detergent (BD40) rather than water only.

The main properties and processing differences of Examples 8 to 13 and Comparative Examples C2-C3 have been summarised in Table 3 below. The mass per unit area of the samples was spread across a range of 327 to 386 g/m^2. The packing densities were typically 15% for the compacted media and slightly higher than 9% for the uncompacted comparative examples. The thicknesses of the compacted and uncompacted media varied accordingly. Furthermore, there was a small difference in the packing densities of the

media that were compacted in 3 or 6 stages, respectively. More significant was the increase of the achieved packing density from typically 13% for the media of 200 g/m^2 mass per unit area to approximately 15% for the media of 400 g/m^2.

The compaction of non-woven media also leads to a much improved surface smoothness or a reduction of loose fibre ends. In particular Figure 27 is a series of photographs illustrating side views of examples C3, 12 and 11 (from top to bottom). Two photographs are provided for each example. The photographs on the right side of Figure 27 show the back of the filter media which is the side of the fabric that the needles first entered during needle punching. The photographs on the left side show the front of the filter media and needles entered the front during needle punching after treatment of the back of the filter media. The number of loose fibre ends decreases from Example C3 to Example 11 and the front of examples 11 and 12 also have less loose fibre ends than the back of the filter media. This superior fabric smoothness is typical of compacted filter media, if compared to plain needle felts. Compacted filter media also differ from spunlaced filter media by leaving the fabric structure essentially unchanged as well as by the lack of grooves that are typically present on spunlaced media from the action of the water jets.

Table 3: Fabric properties and processing parameters of Examples 8-13 and Comparative Examples C2-C3.
Spin finish (Sf) options: I = insoluble / hydrophobic; S = soluble / hydrophilic

Example	Mass per unit area [g/m^2]	Thick-ness [mm]	Packing Density [%]	Needle Punch [ins./cm^2]	Com-pacting	Sf	Cleaning Solvents
8	352	2.5	15.3	2x 125	2x 3-substage	I	DCM, Water
9	327	2.4	14.8	2x 125	2x 3-substage	I	DCM, BD40
10	386	2.9	14.6	2x 125	3-substage	I	DCM, BD40
C2	386	4.6	9.2	2x 125	No	I	-
11	384	2.6	16.0	2x 125	2x 3-substage	S	Water
12	384	3.0	14.3	2x 125	3-substage	S	Water
13	352	2.7	14.5	2x 125	3-substage	S	BD40
C3	381	4.4	9.5	2x 125	No	S	-

The filtration efficiencies of Examples 8-10 and of Comparative Example C2 are plotted in Figure 15. The results show a clear increase in filtration efficiency over the 200 g/m^2 counterparts shown in Figure 11. Pressure drop is also plotted in Figure 16 and perhaps not surprisingly, the 400 g/m^2 had a higher pressure drop than the 200 g/m^2 (see Figure 12). However, a comparison of the results in Figure 13 (200 g/m^2) and Figure 17 (400 g/m^2) for Q as well as Figure 14 (200 g/m^2) and Figure 18 (400 g/m^2) for Q_x suggested that differences were comparably small.

If the comparison was extended to include results from fabrics made from polypropylene fibres with

hydrophilic spin finish, we noticed an additional increase in the respective filtration efficiencies (Figure 19) at comparable pressure drop values (Figure 20). While the resulting values for the quality factors Q (Figure 21) and Q_x (Figure 22) were initially relatively similar to those of the counterparts with hydrophobic spin finish residues (Figures 17 and 18), the respective values for 3 and 22 days after charging maintained significantly higher values. It was consistent with our experience that fibres with hydrophilic spin finish could be cleaned more easily and more effectively than fibres with hydrophobic spin finish.

Examples 14 - 15

Examples 14 and 15 had their Dust Loading Performances evaluated under the influence of a continuous dust challenge from the unused state to a completely discharged state, while pressure drop and filtration efficiency were monitored according to the methodology described in the invention. Such a "Dust Loading Test" can take several hours to complete. The physical properties of example 14 (50d) were evaluated 50 days after electrostatic charging and the properties of example 14 (129d) were evaluated 129 days from charging. The mass per unit area of the examples was close to 400 g/m^2 and a packing density in the order of 16% for Example 14 and 19% for Example 15. Details of the fabric properties and processing parameters are set out in Table 4 below.

Example 14 was compacted by being passed once through the washing and compacting substage shown in Figure 2. Example 15 was passed twice through the washing and compacting substages shown in Figure 2 which is equivalent to a 6- substages process. While the treatment of Example 14 involved the use of non-ionic detergent (BD40) in the first stage only, the same 0.1% concentration of detergent was used for Example 15 in stages 1 and 2. All other treatments for examples 14 and 15 were otherwise the same.

Table 4: Fabric properties and processing parameters of Examples 14-15, evaluated at different times from charging ("50d" = 50 days from charging). Spin finish (Sf) options: I = insoluble / hydrophobic; S = soluble / hydrophilic.

Example	Mass per unit area [g/m^2]	Thick-ness [mm]	Packing Density [%]	Needle Punch [ins./cm^2]	Com-pacting	Sf	Washing Solvents
14 (50d)	378	2.5	16.4	2x 125	3-substages	S	BD40
14 (129d)	368	2.5	16.3	2x 125	3-substages	S	BD40
15 (49d)	366	2.2	18.6	2x 125	2x 3-substages	S	BD40
15 (128d)	386	2.1	19.9	2x 125	2x 3-substages	S	BD40

The filtration efficiency at increasing levels of dust load challenge (Dust Loading Test) are plotted for Examples 14 and 15 in Figure 23. The values remained remarkably constant up to a total dust load challenge of 14 g/m^2. It is possible that the usual "dip" in filtration efficiency did not occur in this instance because the media had had plenty of time to reach a stable electrostatic equilibrium after they were charged by DC corona. The "dip" was caused by the presence of unstable excess charge that does normally dissipate within 3 days from charging. For dust loads greater than 14 g/m^2 the filtration efficiency started to increase, which was due to mechanical clogging of the filter medium by the collected dust. In the time period from 50 days to 129 days from charging, the media of both examples exhibited an overall drop in the filtration efficiency, which was typically in the order of 10% in magnitude.

Pressure drop measurements are shown in Figure 24 and following a relationship that was typical for Dust Loading Tests. Specifically, the pressure across the

media remained relatively constant at low dust loads, but increases as significant dust deposits started to build on and within each filter medium. The progressive build up of pressure drop happened earlier for the Example 15 due to a higher packing density.

The results further illustrate that a 10% decrease in filtration efficiency, as caused by electrostatic decay over 79 days, led to a delay in the corresponding pressure drop increase. This change was represented by the pressure drop difference between Dust Loading Tests conducted at 50 days and 129 days after charging. The observation can be explained by the reduction of the filtration efficiency, which allowed more dust to pass through the medium without contributing to the dust deposit in the filter structure.

The 10% drop in filtration efficiency that was caused by the decay of electrostatic charge in the medium led to comparable reductions in the respective quality factor dependences for Q (Figure 25) and Q_x (Figure 26). During the course of the Dust Loading Test, as stored electrostatic charge was discharged by dust particles deposited on the fibre surfaces, the quality factors eventually settled in the vicinity of values that were typical of uncharged, purely mechanical filter media. These values were quite universal for the type of nonwoven filter media described in the invention and were given by $Q \approx 7\ kPa^{-1}$ (for a test face velocity of 0.15 m/s) and $Q_x \approx 20\ nm$.

Particle Counter Filtration Efficiency Test

In addition to the MBFTI Test, examples 14 and 15 were also tested using an alternative test instrument known as the Particle Counter Filtration Efficiency Test Instrument (PCFTI).

The design of the PCFTI which we refer to as the "PCFTI" is based on the amalgamation of three filter test standards, namely: the Australian Standard AS 1324.2-1996;

the British "Sodium Flame" Standard BS 3928:1969; and the American National Standard ASHRAE 52.2-1999.

The main distinguishing feature of the PCFTI from the MBFTI, is the determination of the particle concentration in the test duct by means of a laser particle counter-sizer. The atomiser and test duct were constructed according to AS 1324.2-1996 and design parameters in relation to the handling of sodium chloride dust were obtained from BS 3928:1969. The instrument allows the face velocity to be varied between 0.1 m/s and 0.75 m/s during the trials.

The respective trial results for Examples 14 and 15 have been reproduced in Tables 5 to 12. Filtration efficiencies and quality factors have been split into four specific particle ranges with lower limits of 0.3 μm, 0.5 μm, 1.0 μm and 5.0 μm. The pressure drop measurements of the PCFTI (P_d) were found to differ from those of the MBFTI. At a face velocity of 0.15 m/s, the MBFTI pressure drop was approximately twice that of the PCFTI.

It should be noted that all PCFTI measurements at 50 days from charging were conducted at a higher test face velocity of 0.27 m/s instead of 0.15 m/s. Results for Example 14 and 15 that were carried out before dust loading have been listed in Tables 5 and 6.

Table 5: PCFTI test results of Example 14 at 50 days, before dust loading. Note face velocity (v_f) of 0.27 m/s.

iltration Efficiency %]				P_d	v_f	Q [1/kPa]			Q_x [nm]		
0.3	0.5	1.0	5.0	[Pa]	[m/s]	0.3	0.5	1.0	0.3	0.5	1.0
85.85	92.09	97.09	100	101	*0.27*	19.36	25.12	35.02	94.36	122.43	170.69
85.68	92.26	97.22	100	99	*0.27*	19.63	25.85	36.19	95.68	125.99	176.39
85.79	92.77	96.89	100	98	*0.27*	19.91	26.81	35.41	97.04	130.67	172.59
85.60	92.53	96.91	100	98	*0.27*	19.77	26.47	35.48	96.36	129.01	172.93
85.56	92.35	97.01	100	97	*0.27*	19.95	26.5	36.18	97.24	129.16	176.34

Table 6: PCFTI test results of Example 15 at 49 days, before dust loading. Note face velocity (v_f) of 0.27 m/s.

Filtration Efficiency [%]				P_d	v_f	Q [1/kPa]			Q_x [nm]		
.3	0.5	1.0	5.0	[Pa]	[m/s]	0.3	0.5	1.0	0.3	0.5	1.0
6.67	92.93	96.95	100	110	*0.25*	18.32	24.08	31.73	84.49	111.05	146.33
6.96	92.63	97.46	98.9	108	*0.27*	18.86	24.15	34.01	91.92	117.71	165.76
6.46	92.72	97.17	100	107	*0.27*	18.69	24.49	33.32	91.09	119.36	162.4
7.23	93.33	97.01	100	106	*0.25*	19.42	25.54	33.11	89.56	117.79	152.7
6.99	92.79	97.1	100	104	*0.25*	19.61	25.29	34.04	90.44	116.63	156.99

Consistent with the corresponding values from the MBFTI dust loading experiments, which were plotted in Figure 23 (filtration efficiency), Figure 24 (quality factor Q) and Figure 25 (quality factor Q_x), the differences between Example 14 and 15 were quite small at the beginning of the test. The same trend seemed to apply also after dust loading, as illustrated by tabulated data in Tables 7 and 8. The filtration efficiency of Example 15 was however significantly higher than that of Example 14 at various intermediate stages of the test, which was a demonstration of the usefulness of the Dust Loading Test method.

Table 7: PCFTI test results of Example 14 at 50 days, after dust loading. Note face velocity (v_f) of 0.27 m/s.

Filtration Efficiency [%]				P_d	v_f	Q [1/kPa]			Q_x [nm]		
0.3	0.5	1.0	5.0	[Pa]	[m/s]	0.3	0.5	1.0	0.3	0.5	1.0
93.05	98.03	99.65	100	465	*0.25*	5.73	8.45	12.16	26.43	38.97	56.08
93.20	98.19	99.7	100	465	*0.27*	5.78	8.63	12.49	28.17	42.06	60.88
92.97	98.25	99.73	100	475	*0.28*	5.59	8.52	12.45	28.7	43.74	63.92
93.06	97.87	99.57	100	475	*0.28*	5.62	8.1	11.47	28.85	41.59	58.89
93.02	97.98	99.59	100	475	*0.27*	5.6	8.21	11.57	27.29	40.02	56.39

Table 8: PCFTI test results of Example 15 at 49 days, after dust loading. Note face velocity (v_f) of 0.27 m/s.

Filtration Efficiency [%]				P_d	v_f	Q [1/kPa]			Q_x [nm]		
0.3	0.5	1.0	5.0	[Pa]	[m/s]	0.3	0.5	1.0	0.3	0.5	1.0
93.68	98.13	99.72	100	480	*0.28*	5.75	8.29	12.25	29.52	42.56	62.89
93.89	98.13	99.73	100	470	*0.28*	5.95	8.47	12.58	30.55	43.49	64.59
93.67	98.12	99.65	100	460	*0.28*	6	8.64	12.29	30.81	44.36	63.1
93.40	97.87	99.72	100	443	*0.27*	6.14	8.69	13.27	29.93	42.35	64.68
93.34	98.04	99.75	100	440	*0.27*	6.16	8.94	13.62	30.02	43.57	66.38

Pertinent PCFTI test results for Example 14 and 15, which had been carried out 129 days from charging, have been tabulated in Tables 8 and 12. The striking similarity of initial and final filter characteristics that was observed for 50 days from charging was still present. The measurements had been carried out at the same face velocity (v_f) as the Dust Loading Tests, which was 0.15 m/s. This allowed a more direct comparison of results between PCFTI and MBFTI.

Table 9: PCFTI test results of Example 14 at 129 days, before dust loading. Note face velocity (v_f) of 0.15 m/s.

Filtration Efficiency [%]				P_d	v_f	Q [1/kPa]			Q_x [nm]		
0.3	0.5	1.0	5.0	[Pa]	[m/s]	0.3	0.5	1.0	0.3	0.5	1.0
91.63	94.97	98.08	100	54	*0.15*	45.94	55.37	73.2	123.91	149.35	197.44
92.28	94.67	98.42	100	53	*0.15*	48.33	55.32	78.26	130.36	149.21	211.09
92.57	95.03	98.63	100	53	*0.15*	49.05	56.64	80.95	132.3	152.77	218.34
92.31	95.31	98.47	100	51	*0.15*	50.3	59.99	81.96	135.67	161.81	221.07
92.55	95.15	98.41	100	50	*0.15*	51.94	60.52	82.83	140.09	163.24	223.41

Table 10: PCFTI test results of Example 15 at 128 days, before dust loading. Note face velocity (v_f) of 0.15 m/s.

Filtration Efficiency [%]				P_d	v_f	Q [1/kPa]			Q_x [nm]		
0.3	0.5	1.0	5.0	[Pa]	[m/s]	0.3	0.5	1.0	0.3	0.5	1.0
93.77	96.58	99.11	100	64	*0.15*	43.37	52.74	73.78	116.98	142.25	199
94.60	96.89	99.11	100	62	*0.15*	47.08	55.98	76.16	126.99	150.99	205.42
94.48	96.55	99.24	99.4	61	*0.15*	47.49	55.19	79.99	128.09	148.86	215.75
94.52	96.99	99.16	100	58	*0.15*	50.07	60.4	82.41	135.05	162.91	222.28
94.51	96.89	99.15	100	58	*0.15*	50.04	59.84	82.2	134.97	161.4	221.71

Table 11: PCFTI test results of Example 14 at 129 days, after dust loading. Note face velocity (v_f) of 0.15 m/s.

Filtration Efficiency [%]				P_d	v_f	Q [1/kPa]			Q_x [nm]		
0.3	0.5	1.0	5.0	[Pa]	[m/s]	0.3	0.5	1.0	0.3	0.5	1.0
90.25	95.46	99.01	100	155	*0.16*	15.02	19.95	29.78	44.45	59.04	88.13
90.43	95.71	98.93	100	154	*0.16*	15.24	20.45	29.46	45.1	60.52	87.18
90.61	95.79	98.98	100	153	*0.16*	15.46	20.7	29.97	45.75	61.26	88.69
90.15	95.64	99.04	100	154	*0.16*	15.05	20.34	30.17	44.54	60.19	89.28
90.16	96.02	98.98	99.7	150	*0.15*	15.46	21.49	30.57	41.7	57.96	82.45

Table 12: PCFTI test results of Example 15 at 128 days, after dust loading. Note face velocity (v_f) of 0.15 m/s.

Filtration Efficiency [%]				P_d	v_f	Q [1/kPa]			Q_x [nm]		
0.3	0.5	1.0	5.0	[Pa]	[m/s]	0.3	0.5	1.0	0.3	0.5	1.0
93.30	97.09	99.65	100	203	*0.16*	13.32	17.42	27.86	39.42	51.55	82.45
94.31	97.73	99.49	100	200	*0.16*	14.33	18.93	26.39	42.41	56.02	78.1
94.42	97.93	99.53	100	192	*0.16*	15.03	20.2	27.92	44.48	59.78	82.62
94.31	97.6	99.52	100	185	*0.15*	15.49	20.16	28.86	41.78	54.38	77.84
94.32	97.42	99.52	100	182	*0.15*	15.76	20.1	29.34	42.51	54.21	79.14

A comparison of filtration efficiency averages from PCFTI measurements for particles of 0.3-0.5 μm in

size to corresponding average values from MBFTI dust loading have been summarised in Table 13. The PCFTI values were averages of 5 individual measurements, as listed in the tables above. The MBFTI averages were evaluated from the first two dust load readings (start) or the last two readings (end), respectively.

Table 13: Comparison of PCFTI and MBFTI filtration efficiencies (FE) for Example 14 and 15, before and after dust loading.

Example	Dust Loading	Time	FE PCFTI	FE MBFTI
14	before / start	129 d	92.3	82.0
14	after / end	129 d	90.3	85.7
15	before / start	128 d	94.4	85.0
15	after / end	128 d	94.1	88.6

Results indicated that the MBFTI produced generally lower readings than the PCFTI. It was further consistent with our experience that differences between the two test instruments were usually larger for electrostatically charged filter media, if compared to discharged counterparts or predominantly uncharged filter media.

By comparing results from Tables 5 and 9, the differences between quality factors Q_x were much smaller than those of Q. This was because the results of Table 5: had been determined at a higher face velocity of 0.27 m/s and only Q_x takes changes of face velocity into account. Despite the correction, the Q_x values for a face velocity of 0.27 m/s were still lower than those for 0.15 m/s, even though we knew from MBFTI dust loading results that the

difference should have had the opposite sign. The reason for this could be founded in the strength of the electrostatic force inside the filter medium, which may be less effective in capturing dust particles at higher face velocities. It should be noted that the correction implemented in the definition of Q_x does only account for the pressure drop response to a change of face velocity and ignores the more complex association with changes in filtration efficiency.

In addition to the above, as a result of the manner in which MBFTI tests are conducted, the changes in the filtration properties shown in Figures 7 to 22 are the result of a combination of two effects: the temporal decay of non-permanent electrostatic charge and the depletion of the electrostatic charge caused by fine particles being deposited on fibres of the filter medium during the test.

In contrast, the results of the trials of the Dust Loading Tests shown in Figures 23 to 26 demonstrate that the changes in filtration properties for these tests were in essence the result of the electrostatic charge depleting in response to the medium being loaded with fine particles. Temporal decay of the electrostatic charge during the test was negligible.

Finally, as a result of the manner in which the PCFTI tests were conducted, the results of these trials are effectively assessing the filtration properties of the filter medium in unaltered form, i.e. without electrostatic charge being depleted by captured particles from the test. In other words, temporal changes to the filtering properties of the filter medium are the direct result of temporal decay of non-permanent electrostatic charge.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A process for treating a fabric that can be used as an electrostatic filter medium, the process including the steps of:

a) compacting a non-woven web of fibres, or at least a portion thereof, by way of a mechanical means while the non-woven web or said portion is in contact with a liquid phase, and wherein the non-woven web contains one or more than one type of staple fibre;

b) drying the web of fibres; and

c) electrostatically charging the compacted web of fibres to enhance the capacity of the web to filter dust particles from a gas.

2. The process according to claim 1, including a step of washing the non-woven fibrous web to remove antistatic agents using a washing liquid.

3. The process according to claim 2, wherein the washing liquid is the liquid phase that is in contact with the non-woven web during step a).

4. The process according to claim 2 or 3, wherein the washing liquid includes any one or a combination of the following: an organic solvent, liquid carbon dioxide, water, or a detergent.

5. The process according to any one of claims 2 to 4, wherein the step of washing the web involves the web travelling through one or more than one reservoir of the washing liquid.

6. The process according to any one of claims 2 to 5, wherein the step of washing the web involves the web travelling through two or more washing reservoirs and the step of compacting the web is to some extent carried out on the web after travelling through each washing reservoir.

7. The process according to any one of the preceding claims, wherein the staple fibres in the web are any one or a combination of cellulosic fibres, keratin fibres, proteinaceous fibres or synthetic fibres.

8. The process according to claim 7, wherein the synthetic fibres including polymers in the form of any one or a combination of polyolefins, polyesters, polycarbonates, polyamides, polyurethanes, polyaramids, polyacrylonitriles, polyacrylics, polyvinyls, polyvinylidenes, polytetrafluoroethylene and respective polymer-copolymer-combinations and variations thereof.

9. The process according to any one of the preceding claims, wherein the mechanical means used for carrying out step a) defines an opening through which the web passes and the opening has a height that is less than the thickness of the web prior to compaction.

10. The process according to any one of the preceding claims, wherein the mechanical means is a nip between one or more pairs of rollers and that step a) involves passing the web through the nip(s).

11. The process according to claim 10, wherein each pair of roller(s) apply a compacting force ranging from 5 to 100 kN/m to the web.

12. The process according to claim 10, wherein each pair of roller(s) apply a compacting force to the web of approximately 10kN/m.

13. The process according to any one of the preceding claims, wherein prior to step a) being carried out, the web of fibres undergoes an initial consolidation stage.

14. The process according to claim 13, wherein the initial consolidation stage involves any one or a combination of needle punching, spunlacing or hydroentangling, calendering, or thermal bonding.

15. The process according to claim 13 or 14, wherein the packing density of the fabric after initial consolidation ranges from 2% to 10%.

16. The process according to any one of claims 1 to 15, wherein the web, once treated according to step a) has a packing density ranging from 5 to 30%.

17. The process according to any one of claims 1 to 15, wherein once treated according to step a), the web has a packing density ranging from 10 to 20%.

18. The process according to any one of claims 1 to 17, wherein the step of drying the web can be carried out using any suitable fan-forced or convective heating means.

19. The process according to any one of claims 1 to 18, wherein step c) involves exposing the web to corona discharge.

20. An electrostatic filter medium manufactured by the process according to any one of claims 1 to 19.

21. An electrostatic filter medium including a non-woven web containing one or more than one type of staple fibre, wherein the non-woven web is electrostatically charged and is compacted such that the electrostatic charge contributes to the filtration properties of the medium for a period of at least 100 days.

22. The filter medium according to claim 21, wherein the electrostatic charge contributes to the filtration capacity of the medium for at least 365 days.

23. The filter medium according to claim 21 or 22, wherein the web is wet compacted whereby compaction occurs while at least part of the web is in contact with a liquid.

24. The filter medium according to claim 23, wherein any one or more of the following properties of the filter medium is greater or superior than the same property of a filter medium of the same makeup and at substantially the same base weight (g/m^2) without wet compaction: filtration efficiency(%), quality factor Q (kPa^{-1}) or quality factor Q_x(nm).

25. The filter medium according to any one of claims 21 to 24, wherein the weight of the web ranges from 100 to 1000 g/m^2.

26. The filter medium according to any one of claims 21 to 25, wherein the filtration efficiency is at least 20% using a Methylene Blue Filter Test Instrument which is substantially based on the design specification of Australian Standard as 1324.2 - 1996.

27. The filter medium according to any one of claims 21 to 26, wherein the medium has a quality factor Q of at

least 14 kPa^{-1} at a test face velocity of 0.15 m/s for a period of at least 365 days as assessed by a Methylene Blue Filter Test Instrument.

28. The filter medium according to any one of claims 21 to 27, wherein the medium has a quality factor Q_x of at least 40 nm for a period of at least 365 days as assessed by a Methylene Blue Filter Test Instrument.

29. The filter medium according to any one of claims 21 to 28, wherein the medium has a packing density of at least 10%.

30. The filter medium according to claim 21, wherein when the base weight of the web ranges from 200 to 300 g/m^2 and has a packing density greater than 5%, the filter has any one or a combination of the following properties as assessed by a Methylene Blue Filter Test Instrument:

- a filtration efficiency of at least 30% for a period of at least 365 days;
- a quality factor Q of at least 14kPa^{-1} for a period of at least 365 days;
- a quality factor Q_x of at least 40nm for a period of at least 365 days.

31. The filter according to claim 21, wherein when the base weight of the web ranges from 200 to 300 g/m^2 and has a packing density greater than 10%, the filter has any one or a combination of the following properties as assessed by a Methylene Blue Filter Test Instrument:

- a filtration efficiency of at least 40% for a period at least 4 days;
- a quality factor Q of at least 10kPa^{-1} for a period of at least 4 days;
- a quality factor Q_x of at least 28nm for a period of at least 4 days.

32. The filter according to claim 31, wherein the filter has any one or a combination of the following properties as assessed by a Methylene Blue Filter Test Instrument:

- a quality factor Q of at least 14kPa^{-1} for a period of at least 4 days;

- a quality factor Q_x of at least 40nm for a period of at least 4 days.

33. The filter medium according to claim 21, wherein when the base weight of the web ranges from 300 to 400 g/m^2, has a packing density greater than 10%, and has a hydrophobic spin finish the filter has any one or a combination of the following properties as assessed by a Methylene Blue Filter Test Instrument:

- a filtration efficiency of at least 55% for a period at least 4 days;
- a quality factor Q of at least $10kPa^{-1}$ for a period of at least 4 days;
- a quality factor Q_x of at least 28nm for a period of at least 4 days.

34. The filter medium according to claim 21, wherein the base weight of the web ranges from 300 to 400 g/m^2, has a packing density greater than 10%, and has a hydrophilic spin finish the filter has any one or a combination of the following properties as assessed by a Methylene Blue Filter Test Instrument:

- a filtration efficiency of at least 55% for a period of at least 20 days;
- a quality factor Q of at least $14kPa^{-1}$ for a period of at least 20 days;
- a quality factor Q_x of at least 40nm for a period of at least 20 days.

35. The filter medium according to claim 21, wherein when the base weight of the web ranges from 300 to 400 g/m^2, has a packing density greater than 10%, and has a hydrophilic spin finish the filter has any one or a combination of the following properties as assessed by a Methylene Blue Filter Test Instrument:

- a filtration efficiency of at least 80% for dust loading of up to 8 g/m^2 for a period at least 128 days;
- a quality factor Q of at least $10kPa^{-1}$ for a dust loading of up to 8 g/m^2 for a period at least 128 days;
- a quality factor Q_x of at least 28nm for a dust loading of up to 8 g/m^2 for a period at least 128 days.

36. The filter medium according to claim 21, wherein when the base weight of the web ranges from 300 to 400 g/m^2, has a packing density greater than 10%, and has a hydrophilic spin finish, the filter has any one or a combination of the following properties as assessed by a Methylene Blue Filter Test Instrument:

- a filtration efficiency of at least 80% for dust loading of up to 2 g/m^2 for a period at least 128 days;
- a quality factor Q of at least 14kPa^{-1} for a dust loading of up to 2 g/m^2 for a period at least 128 days;
- a quality factor Q_x of at least 40nm for a dust loading of up to 2 g/m^2 for a period at least 128 days.

37. The filter medium according to any one of claims 30 to 36, wherein the web consists entirely of 100% polypropylene fibres.

38. A plant for treating a fabric that is suitable for manufacturing an electrostatic filter medium, the plant including:

mechanical compacting means in which a non-woven web of fibres, or at least a portion thereof, is compacted while the non-woven web or said portion thereof is in contact with a liquid, and wherein the non-woven web contains one or more than one type of staple fibres;

a drying stage in which the liquid is dried from the compacted non-woven web; and

means for electrostatically charging the compacted web to enhance the capacity of the web to filter dust particles from a gas.

39. The plant according to claim 38, wherein the plant further include a washing stage in which a washing liquid can remove antistatic agents, such as but by no means limited to, waxes, oils and spin finishes from the exterior of the fibres of the web.

40. The plant according to claim 38, wherein the washing liquid is the liquid in contact to the non-woven web during the compacting stage.

41. The plant according to claim 39 or 40, wherein the washing stage includes one or more than one vessel through which the web travels.

42. The plant according to claim 41, wherein that each vessel includes one or more rollers that define a path submerged in the washing liquid along which the web travels.

43. The plant according to any one of claims 39 to 42, wherein the washing stage includes two or more than two vessels and that the mechanical compacting means include a series of substages each located after the vessels and are adapted for compacting the web to some extent after each washing vessel.

44. The plant according to any one of claims 39 to 43, wherein the compacting means includes a nip formed between two rollers between which the web passes.

45. The plant according to claim 44, wherein the nip provides a compression force ranging from 5 to 100 kN/m to the web as it passes there through.

46. The plant according to any one of claims 38 to 45, wherein the drying stage includes an oven arrangement.

47. The plant according to any one of claims 38 to 46, wherein the means for electrostatic charging exposes the web to corona discharge.

48. The plant according to any one of claims 38 to 47, wherein the plant includes an initial treatment stage for consolidating the web prior to compacting while the web is in contact with a liquid phase.

49. The plant according to claim 48, wherein the initial consolidation stage is in the form of any one or a combination of needle punching, spunlacing or thermal bonding.

Figure 1

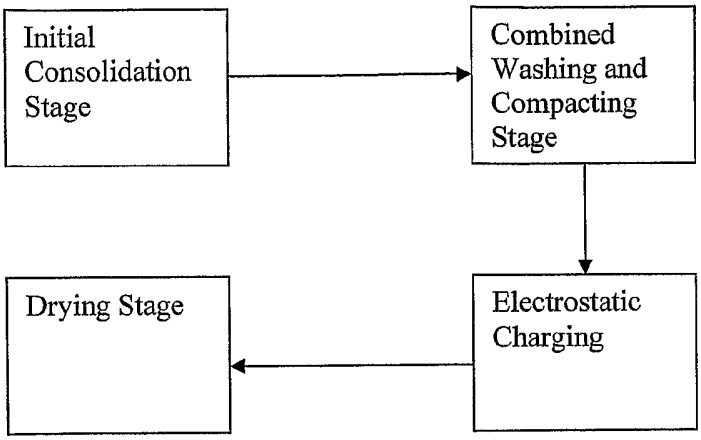


Figure 2

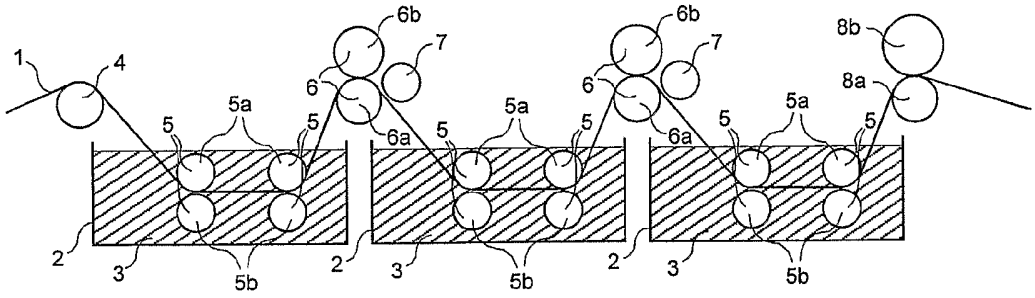


Figure 3

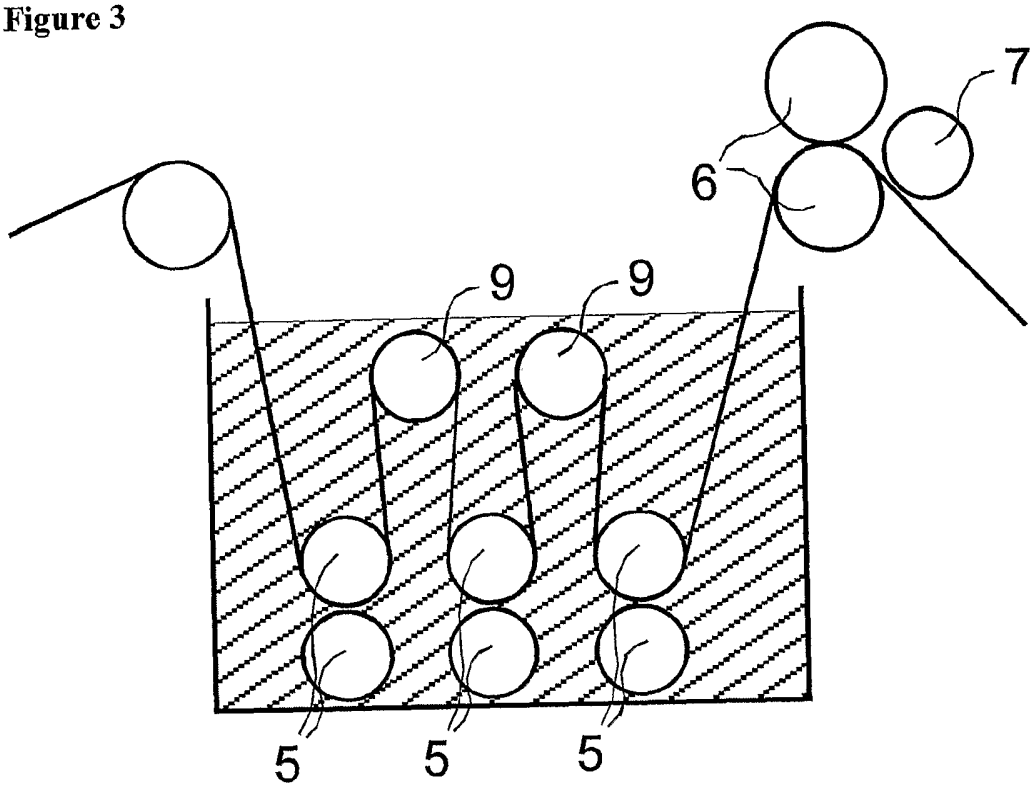


Figure 4

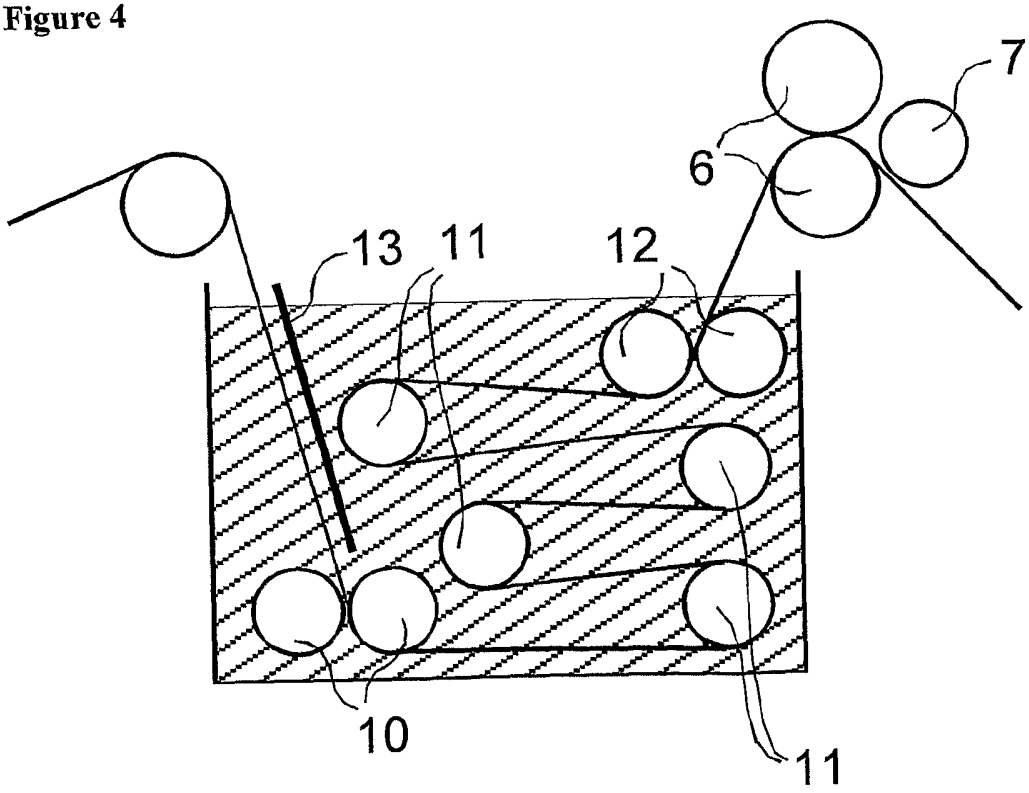


Figure 5

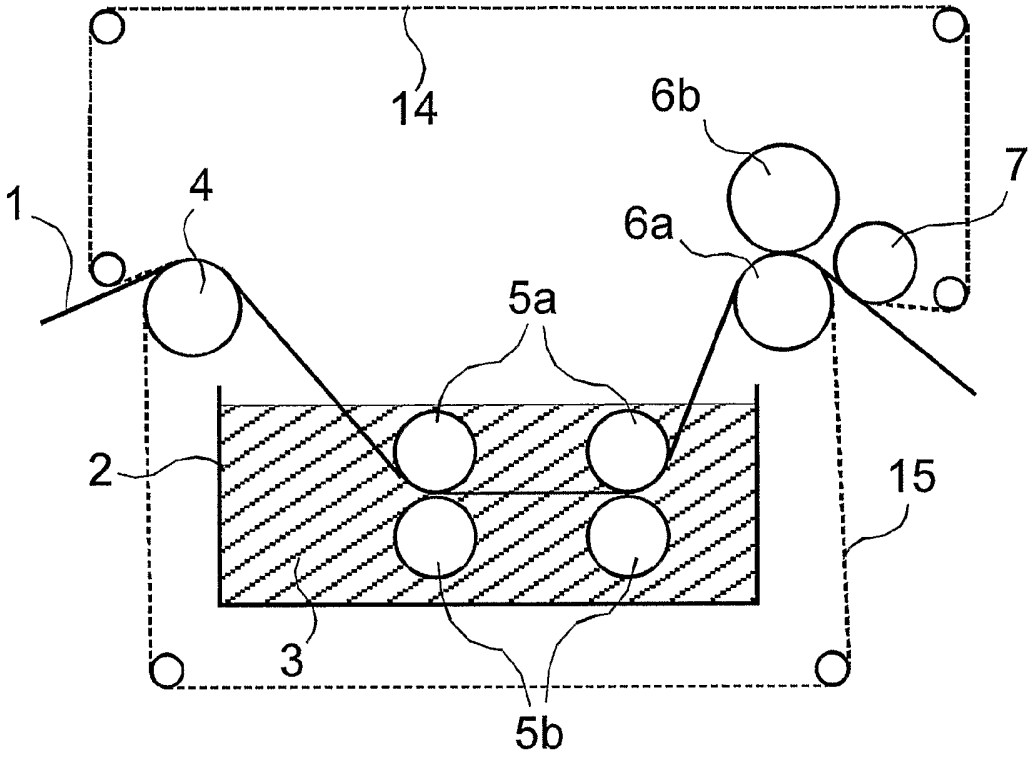


Figure 6a

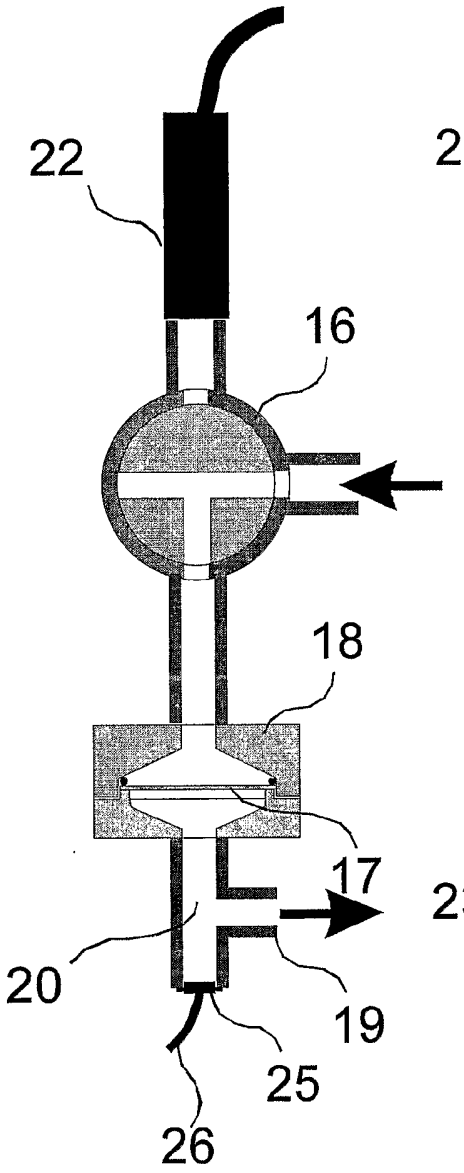


Figure 6b

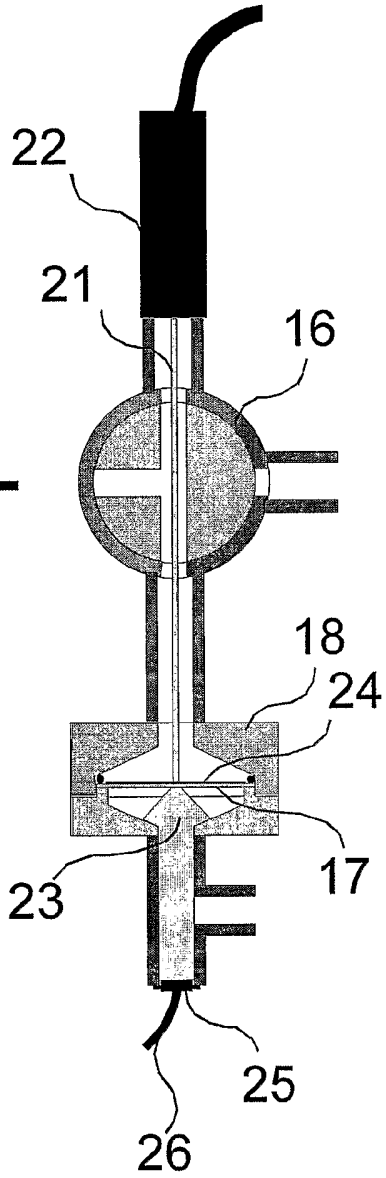


Figure 7

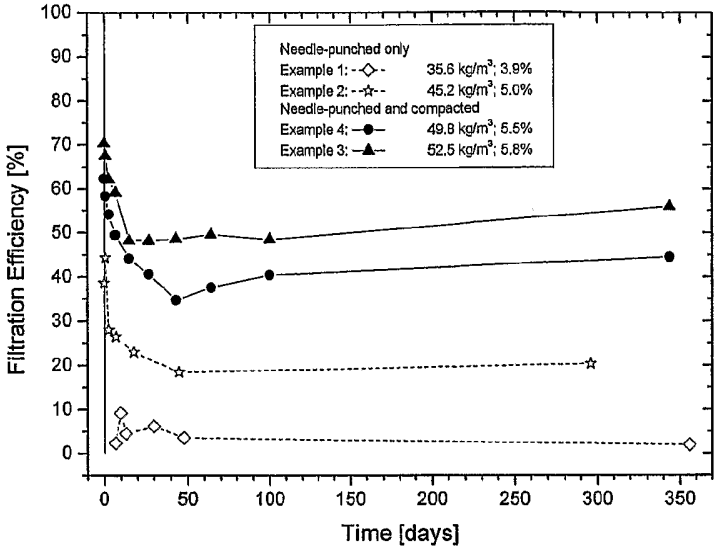


Figure 8

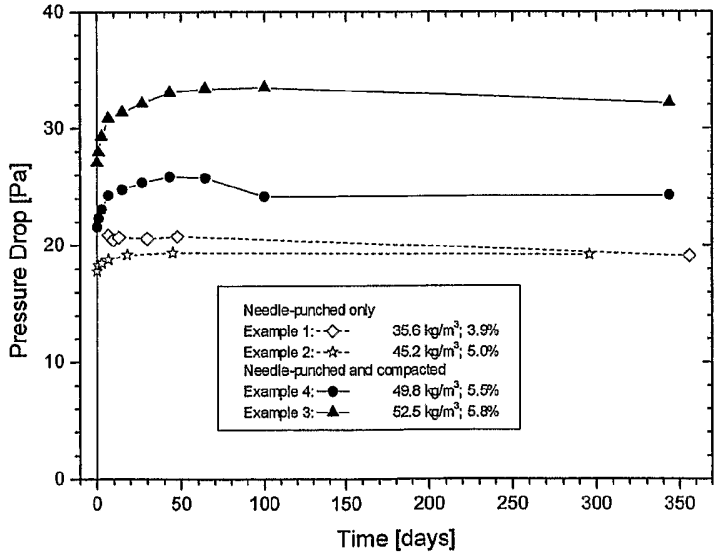


Figure 9

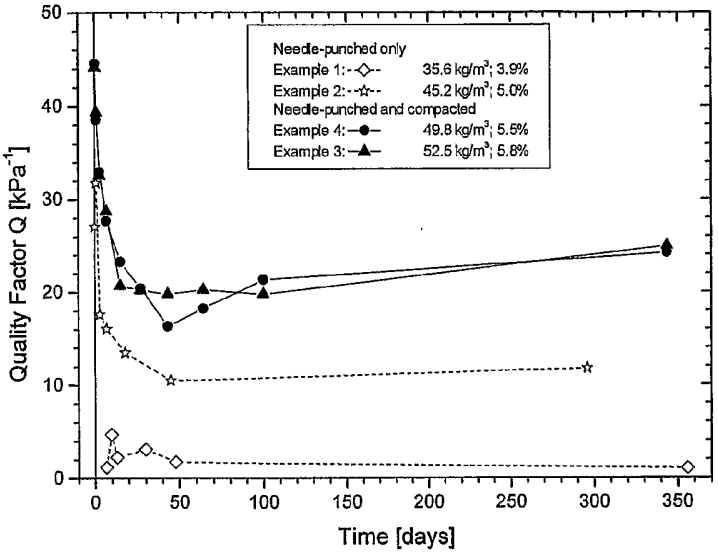


Figure 10

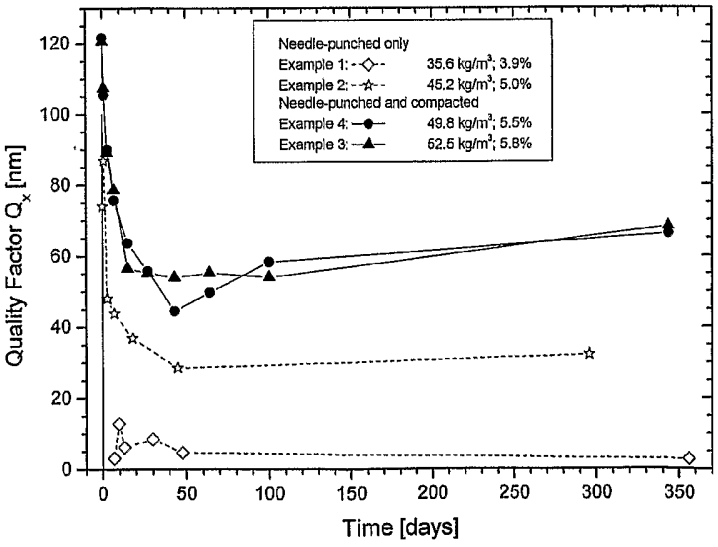


Figure 11

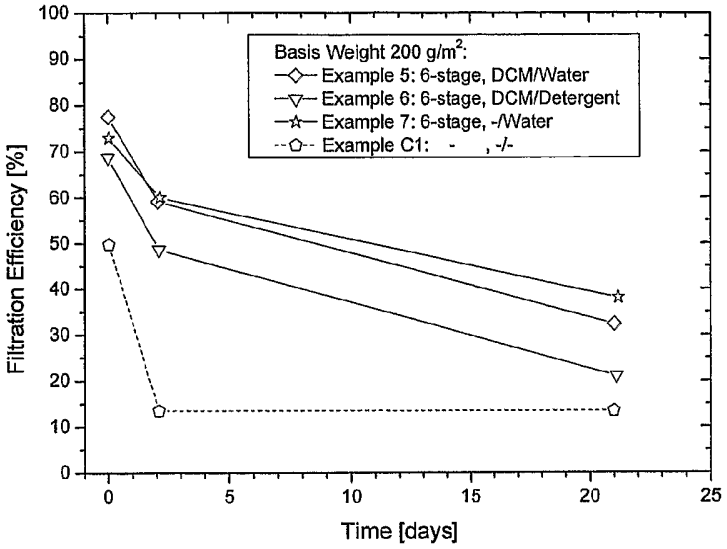


Figure 12

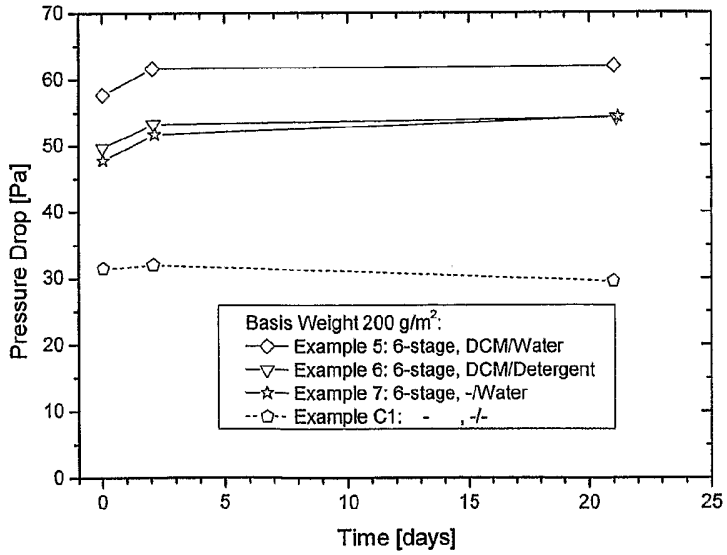


Figure 13

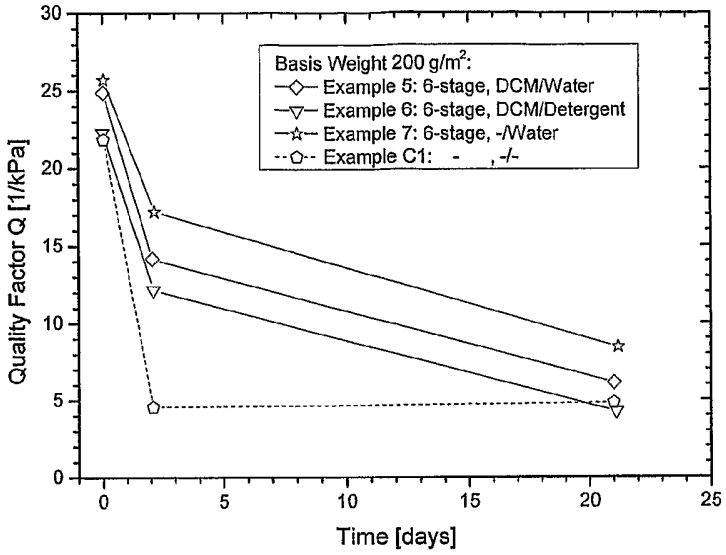


Figure 14

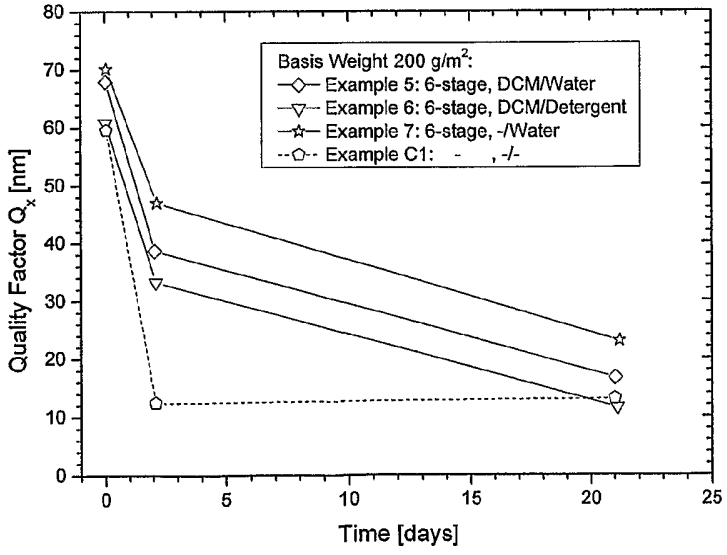


Figure 15

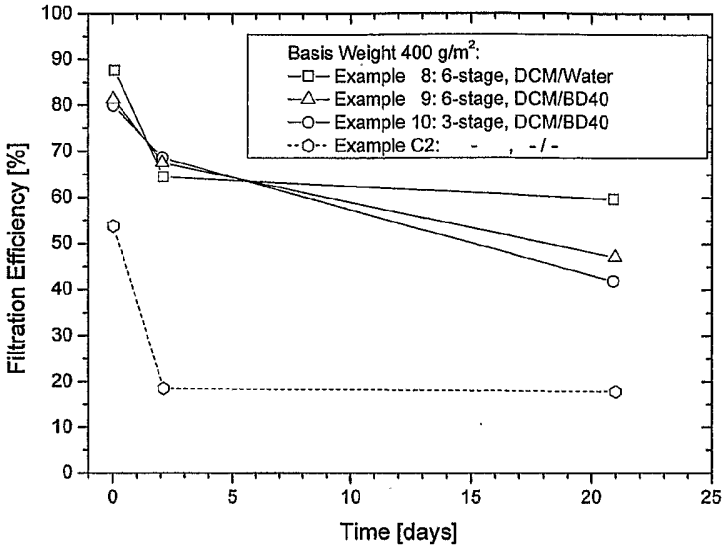


Figure 16

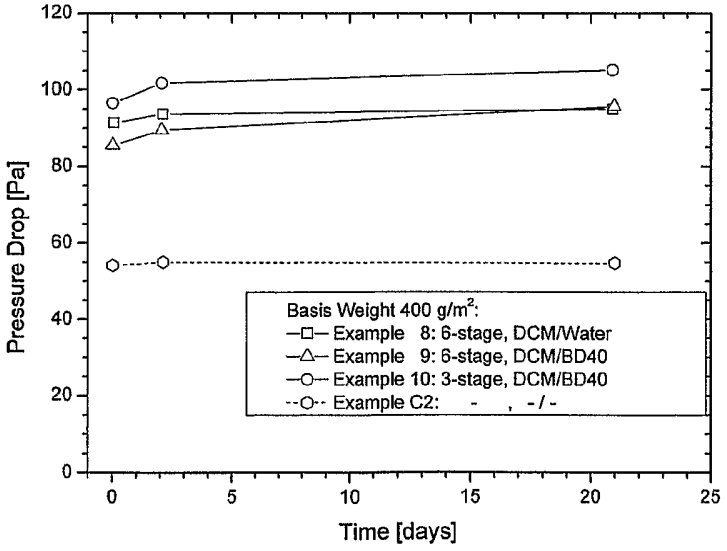


Figure 17

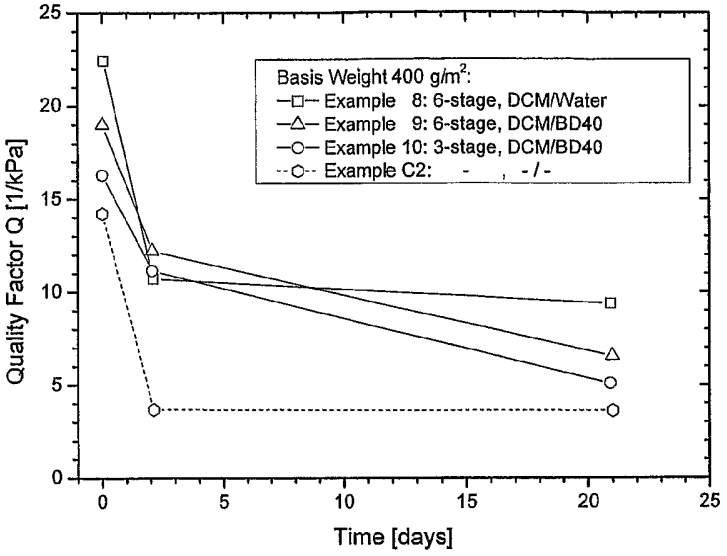


Figure 18

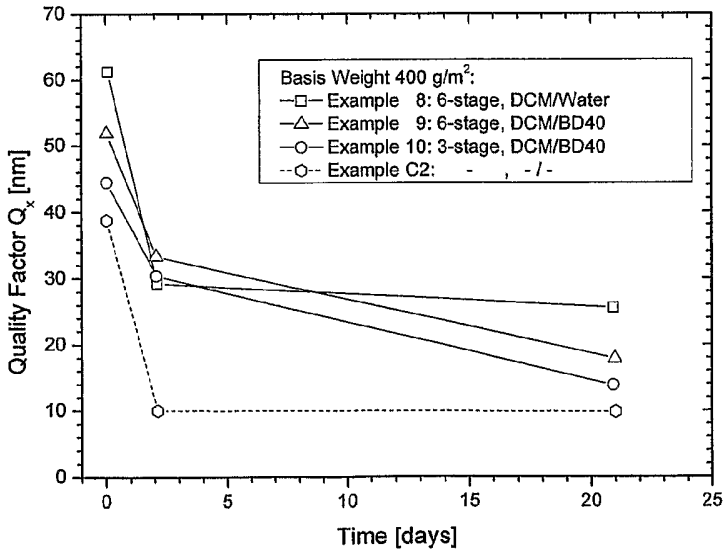


Figure 19

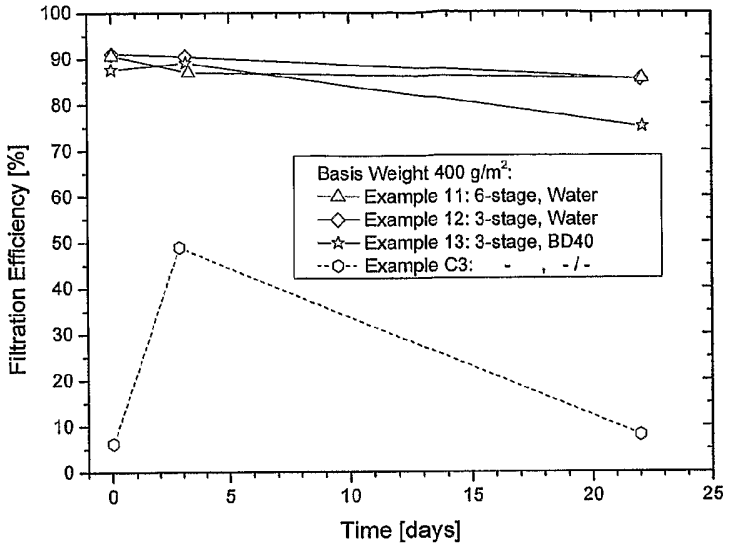


Figure 20

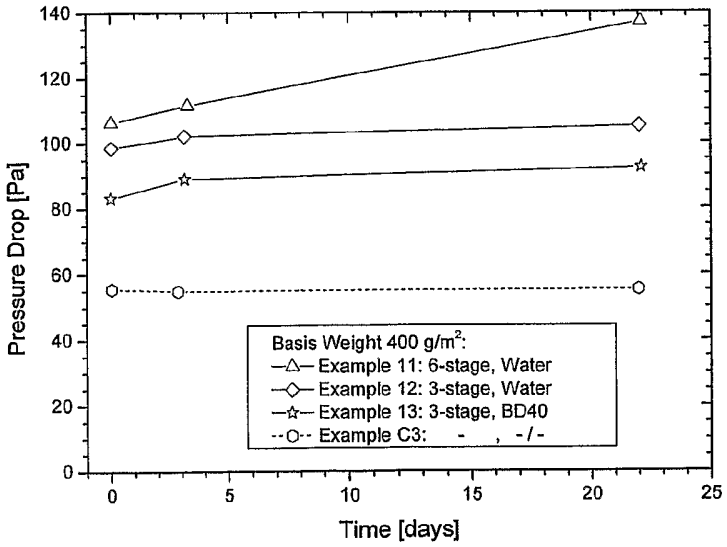


Figure 21

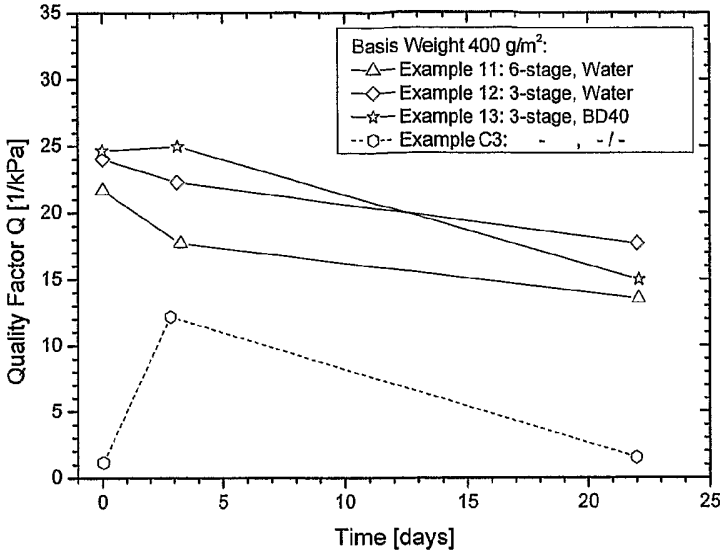


Figure 22

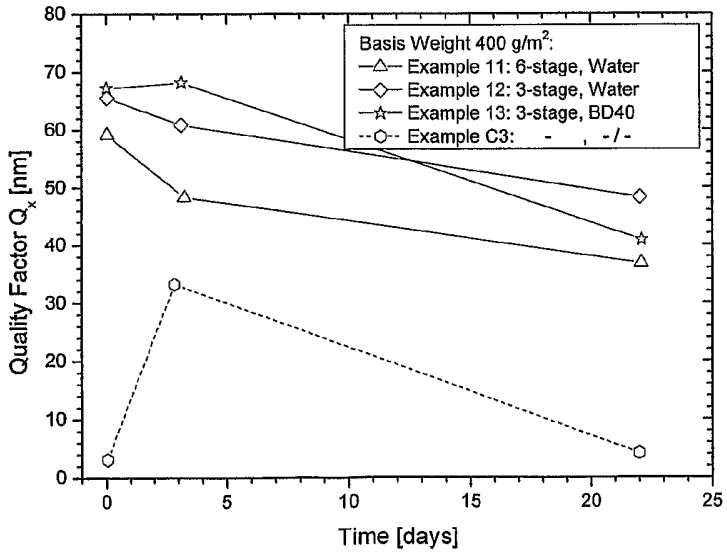


Figure 23

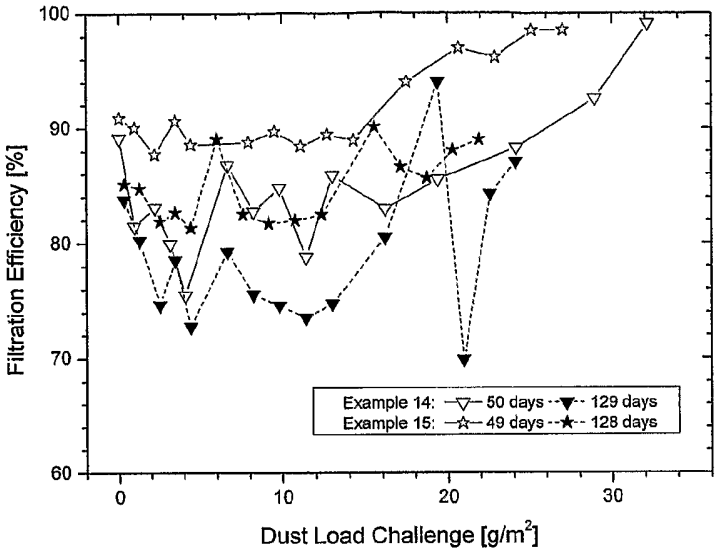


Figure 24

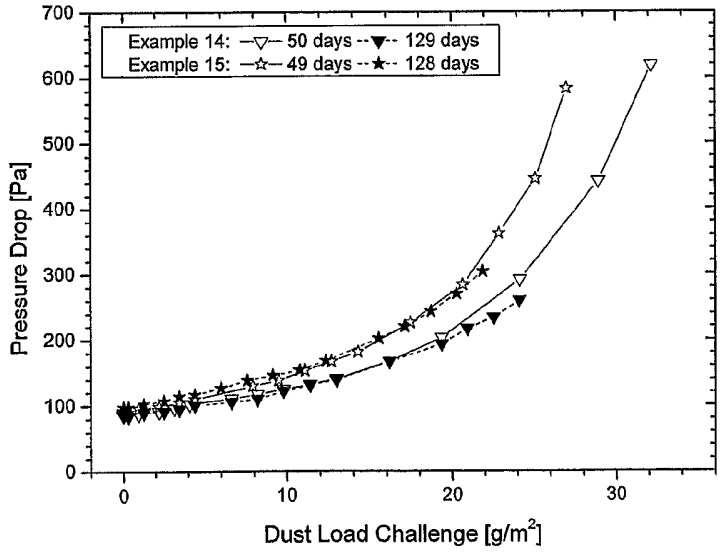


Figure 25

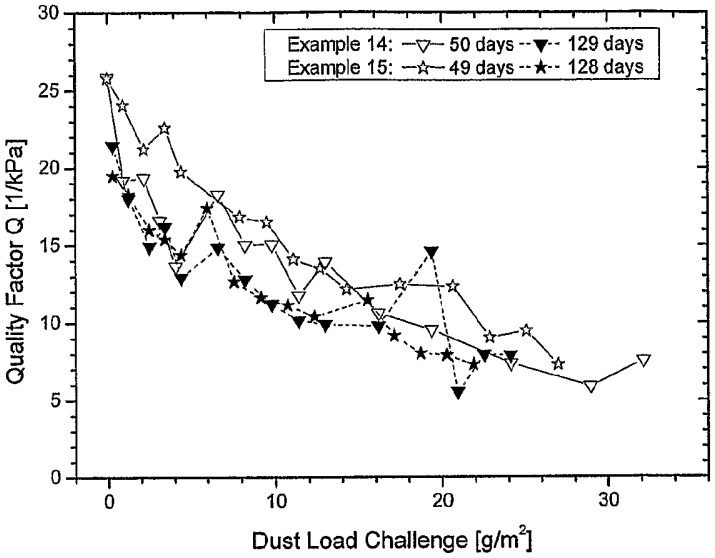


Figure 26

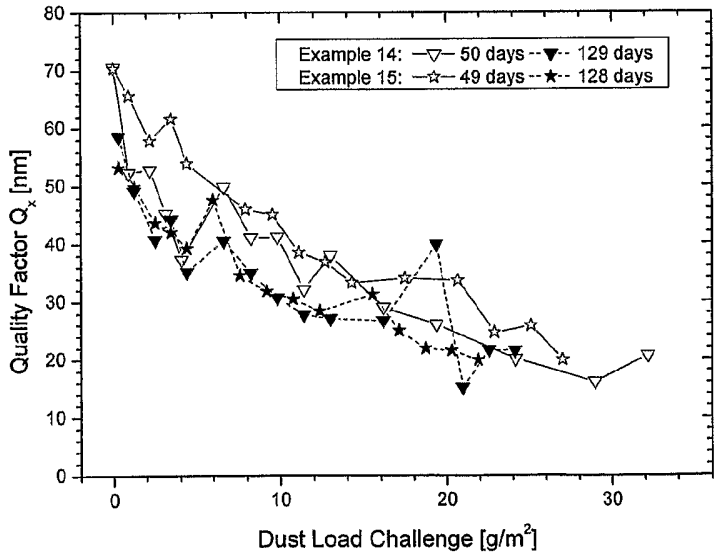
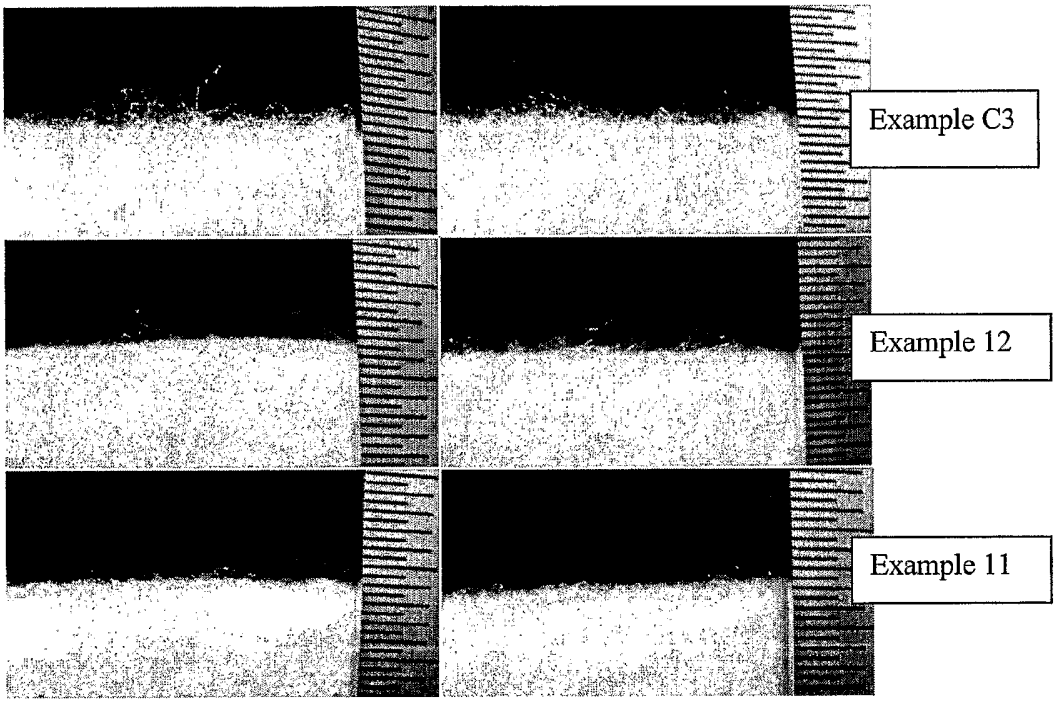


Figure 27



INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2006/000738

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

D04H 1/44 (2006.01) ***B03C 3/28*** (2006.01)
B01D 39/16 (2006.01) ***D04H 1/10*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI IPC D04H1/44, 1/12, 1/10, B01D39/14, 1/16, 1/18, B03C3/00, 3/28 and Keywords;
USPTO and Keywords; esp@cenet and Keywords

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002/0190434 A (EITZMAN ET AL.) 19 December 2002 See especially figures 1-2, paragraphs [0044]-[0049], [0075]	1-49
X	WO 2001/027371 A (3M INNOVATIVE PROPERTIES COMPANY) 19 April 2001 See abstract, figure 1	1-4, 7-8, 13-18, 20-40, 46, 48-49
X	WO 2004/037372 A (POLYMER GROUP, INC.) 6 May 2004 See figure 1, abstract, page 11 lines 17-20	1-4, 7-8, 13-18, 20-40, 46, 48-49
X	WO 2001/021283 A (INTERSURGICAL LIMITED) 29 March 2001 See whole document	21-22, 25-37

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 June 2006	21 JUN 2006
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer **JOHN DEUIS** Telephone No : (02) 6283 2146

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU2006/000738

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	2002190434	AU	25161/00	BR	0014559	CA	2385770
		CN	1384767	EP	1229988	PL	354171
		US	6406657	US	6824718	WO	0126778
HS	00440049						
WO	0127371	AU	34735/00	BR	0014557	CA	2385788
		CN	1378609	EP	1230453	PL	354175
		US	6375886	US	2002110610		
WO	2004037372	AU	2003277455	CN	1729101	EP	1556216
		US	6942711	US	2004211163		
WO	0121283	AU	74315/00	CA	2383975	EP	1214134
		GB	2355215	GB	2382537		

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX