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Examination of liquid management of sub-compression wadding for chronic venous disorders

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This study has been undertaken to analyse the effect of constructional and physical parameters of different wadding or padding materials on the performance of their fluid transport behavior. For fair comparison, a series of 18 wadding samples have been made from polypropylene fibres using dry laid/needle punching process. The testing is conducted using a laboratory-based prototype capable to describe liquid spreading of a fibrous substrate. Several structural factors of the wadding including fibre linear density, mass per unit area and needling density have been examined. Moreover, the effect of other physical factors, such as application of external pressure (transverse loading) and rate of liquid discharge, is also analyzed. It is found that the spreading rate (wet area per unit time) decreases with an increase in mass per unit area and needling density of the nonwoven sample ($p < 0.01$). Low fibre linear density in the structure shows a poor rate of spreading compared to high-fibre linear density ($p < 0.01$). Increasing the transverse pressure on the wadding stimulates slower spreading ($p < 0.01$). It is recommended to use wadding samples with more porosity and larger pore size to obtain faster spreading of liquid exudates during the course of compression treatment.

Keywords: Liquid management, Nonwoven, Venous ulcers, Wadding, Wicking, Wound care

1 Introduction

Fibrous materials play a significant role in the successful treatment of chronic venous disorders such as venous ulcers, venous oedema, etc[1,2]. Wadding or padding is a nonwoven fibrous structure that is recommended along with the compression system (e.g. bandage or stocking) to protect the crucial areas of the legs, especially the bony prominences, from the high pressure[3,4]. Moreover, the role of wadding is vital in the management of body fluids or exudates that are continuously released from the wounded region during the course of compression treatment[5]. Multilayer compression systems, such as 4-layer bandaging, are used for the extended period of time with minimum dressing change[6-8]. This may cause overheating of the underlying tissues and perhaps, excessive sweat production due to poor air or moisture exchange between the body and surrounding. Clearly, the removal of excess fluid or exudates is extremely important to avoid irritation and to ensure comfort to the patients. Over hydration or even maceration of the underlying tissues is likely to happen if the body fluids are not continuously removed from the affected region. Improper management of excessive wound exudates or other body fluids may delay healing and lead to other complications[9]. The wadding is used underneath the compression bandage and, therefore remains in direct contact with the skin. The interaction of fluids with the wadding is therefore critical, as this determines the ability of wadding to spread the liquid to a wider area, thus helping in faster evaporation and prevention of excess moisture build up. This will also provide better comfort to the patients.

Wadding is a fibrous structure, which is usually formed via needle punching or melts blowing process[5]. The liquid management of wadding is largely unexplored. The study on fluid transport is essential to understand how wadding behaves on interaction with the fluids and what should be an ideal structure for the wadding to obtain more spreading of body fluids to promote faster evaporation or removal. The liquid transport characteristics are largely dependent on the fibrous network of wadding. This transport is highly complex phenomena because of non-uniform capillary network developed by the random orientation of fibres in a nonwoven structure. The preparatory methods, such as a needle-punching process, significantly affect the porous network of wadding substrate[10,11], and therefore could affect its liquid management. A great deal of understanding of the structural parameters of waddings could help doctors or nurses in recommending or selecting ideal padding for the treatment and also to ensure substantial compliance of the multilayer compression product.

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Apart from structure, the physical process involved in the fluid movement can further influence padding performance. The spontaneous transport of a liquid into a fibrous assembly in the absence of external force is usually caused by capillary forces, and is further termed as wicking[12]. The relative amount of liquid involved in the process such as a finite or infinite liquid reservoir could significantly affect the nature of transport. In case of an infinite reservoir (unlimited amount of liquid), the movement depends on direction of liquid flow in the material, e.g. vertical wicking[13]. Unidirectional wicking under such reservoir condition is comparatively slow for bigger capillaries network due to generation of lower capillary force. On the contrary, the nature of spreading or multi-directional wicking under a limited reservoir system is different from unidirectional wicking obtained under unrestricted reservoir condition. The multi-directional wicking results in redistribution of the liquid, and depends on the amount of liquid available for the movement. The kinematics of both the above systems, i.e. limited and unlimited liquid reservoirs are different due to difference in geometry involved and also because of difference in the amount of penetrating liquid, which is practically unlimited for the infinite reservoir system, but finite for the limited reservoir system. For the appraising of wadding, the examination under limited reservoir is more suitable as the amount of body fluid is limited and also the rate of excretion is slow. The transport behavior from a limited or finite reservoir, especially the spreading or transport of fluid on the surface of a fibrous structure is the most interesting case in the evaluation of padding.

Based on the above facts, it can be inferred that the appraising of liquid transport in wadding is a difficult task, which demands a systematic and individual approach to examine the primary processes or kinetics involved under distinctive circumstances. Examination of wadding on a human limb is practically impossible to conduct, and therefore laboratory-based methods are more suitable where similar experimental conditions can be provided to different wadding samples to make fair and noise-free comparisons. Several laboratory-based methods have been reported in the literature, such as direct observation of fluid movement, image analysis techniques, gravimetric method, electrical principle, the use of liquid-sensitive sensors, etc[14-18]. Each of these methods serves the individual purpose of testing has their own special significance and provides useful information to realize the liquid transport performance. Herein, we tested the materials using a newly designed instrument based on capacitive principle[12,16]. In this set up, the fibrous material is placed between parallel plates of a capacitor whose capacitance value keeps on changing as the fluid travels in the structure. It also allows to control the liquid discharge rate, and to apply transverse loading on the testing specimen. It provides valuable information such as the anisotropic nature of liquid spreading, the extent and rate of spreading of liquid in various directions, wet area per unit time, transmissivity, etc. The present work mainly focuses on the evaluation of different needle-punched nonwoven wadding samples. The influence of some structural parameters, such as mass per unit area, needling density and fibre denier of nonwoven, has been examined and reported. Moreover, the effects of transverse loading and the rate of liquid discharge rate on its liquid transport are also studied.

2 Materials and Methods

2.1 Wadding Samples

Different needle-punched nonwoven waddings were used for the examination under limited reservoir source. Table 1 shows the structural characteristics of all samples (sample codes A1 - A18). All the samples were produced from a needle-punched nonwoven machine (Model name: DILO; having opener, card, cross lapper, and needle loom) using polypropylene (PP) fibres. Two different linear densities of PP fibre [2.5 and 6 denier; 1 denier - mass (g) of 9000 m length] were used for the production. Different mass per unit area (100, 200 and 300 g/m^2) and needling density (50E4, 130E4 or 210E4 punches/m^2) for the nonwoven samples were obtained by changing the machine parameters of needle-punched nonwoven machine. The depth of needle penetration was kept constant
(10 mm) for all samples during the production.

2.2 Description of Prototype used for Fluid Transport Measurement

The study under limited reservoir condition was done using a prototype that works on the principle of capacitance, according to which the capacitance of a parallel plate capacitor system changes as in dielectric medium present between the parallel plates varies. It can be described using the following equation:

$$C = \frac{k\varepsilon_o A}{d} \qquad \ldots (1)$$

Table 1 — Details of PolyPropylene needle-punched nonwoven samples
[Fibre length = 51 mm]

Sample code	Fibre denier	Mass per unit area g/m^2	Needling density x10^4 punches/m^2	Thickness mm
A1	2.5	100	50	4.09
A2	2.5	100	130	3.75
A3	2.5	100	210	3.48
A4	2.5	200	50	4.82
A5	2.5	200	130	4.48
A6	2.5	200	210	4.23
A7	2.5	300	50	5.08
A8	2.5	300	130	4.84
A9	2.5	300	210	4.45
A10	6	100	50	4.75
A11	6	100	130	4.12
A12	6	100	210	3.79
A13	6	200	50	5.34
A14	6	200	130	4.97
A15	6	200	210	4.54
A16	6	300	50	6.02
A17	6	300	130	5.74
A18	6	300	210	4.74

where C is the capacitance of the capacitor plate; k, the dielectric constant of the material; ε_o, the permittivity of free space (= 8.854E-12 F.m^{-1}); and A, the area of the capacitor plate. If the liquid spreads in the structure of the textile placed in between the parallel plates of a capacitor, then the dielectric constant of the medium will vary, and this will finally change the capacitance value. This change in capacitance values can be tracked and used for analysis of liquid transport.

The main body of the present set up consists of two parallel discs (upper and lower) having a radius as 12 cm. Each disc is embedded with eight capacitor plates of 11 cm length and 4mm width, as shown in Fig. 1(a). When the above two discs are folded then eight parallel plate capacitors are generated on a circular expanse at an angle of 45° to adjacent ones. The instrument is equipped with a control system for pouring liquid at the center of a circular textile specimen from a burette via a flow tube which is connected at the bottom of a burette. The control system is equipped with an IV drip system, which helps to maintain constant water flow rate throughout the experiment. For the simplicity, we omit the complete description of the instrument. Important details can be found in the study reported by Kumar and Das[16]. As liquid falls on the surface of the testing specimen, it spreads in different directions, which is schematically shown in Fig. 1(b). During transport, the liquid spreads along the plane of the specimen, which creates a combined system of dry and wet areas. The above dielectrics of the wet and dry

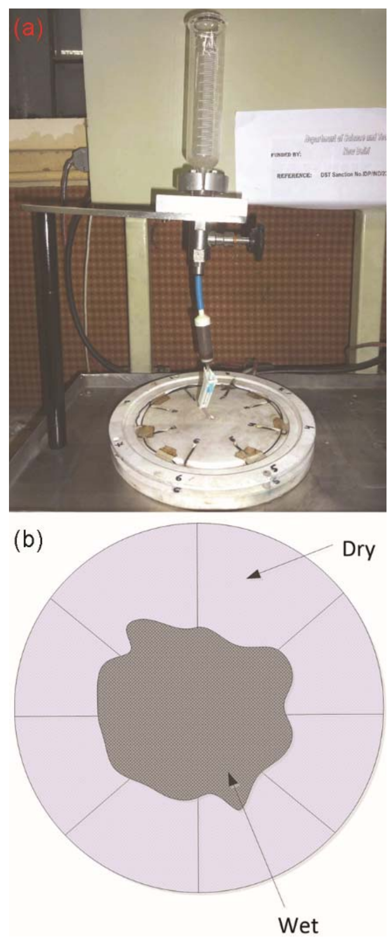

Fig. 1 — (a) Photograph of the instrumental set-up for wicking measuring, and (b) Schematic diagram of liquid transport on a testing

fabrics can be used to calculate the extent of spreading on the surface. Eight capacitors are used to obtain liquid flow behavior in different directions. The distance traveled by liquid along the length of a capacitor [Fig. 1(b)] can be obtained as[12],

$$x = \frac{C_x - C_{dry}}{C_{wet} - C_{dry}} \times L \qquad \text{... (2)}$$

where x is the distance moved by liquid along a capacitor; L, the length of capacitor; C_{dry} and C_{wet}, the capacitance values at completely dry or wet conditions of the specimen respectively, and C_x, its capacitance at a particular moment (t) when the liquid traveled a distance x.

2.3 Experimental Plan

For the experimental plan, different samples from the above set of wadding (sample codes A1 - A18) were carefully chosen to study the individual effect of mass per unit area, needling density and fibre denier. The properties such as pore dimensions, thickness, etc. of nonwoven change under normal stress, and this change in the porous network under confinement could significantly affect the liquid transport through the padding. Therefore, the effect under confinement (transverse pressure) was also analyzed. Different levels of external pressures (0.2, 0.8, 1.5 and 2.0 kPa) were applied to the upper disc by placing the dead weights. These dead weights are circular in shape, which helps to distribute the normal pressure uniformly throughout the testing specimen. Moreover, the effect of different rates of liquid discharge (7.5, 10.5 and 13.5 mL/min) was also examined. Different discharge rates were achieved by adjusting the IV drip system as explained above.

Before conducting the final test, the accuracy of the capacitive measurement of the instrument was checked several times. The least count for the capacitive measurement is ± 0.001 picofarad. The whole testing procedure was ascertained, and the instrument was calibrated after doing many initial trails prior to final testing. A circular testing specimen of radius 11 cm was taken for each individual test. The change in capacitance values was obtained after every 1s for the testing period of 15 min in each experiment to obtain both the kinematics (rate) and the extent of the liquid movement in different directions on the individual testing specimen. Eight different readings (one for each capacitor) for the distance (x) were obtained simultaneously during horizontal spreading. Finally, the total wet area at a particular instant was calculated by summing all the areas generated between two consecutive plates. For each sample, the experiments were conducted five times using different testing specimens. The average of the five experiments was calculated and used for the further comparative analysis of different samples. To perform the significance test for all the above factors, ANOVA (analysis of variance) method was used. A p-value of less than 0.01 was considered as statistically significant.

3 Results and Discussion

Liquid transport characteristics of wadding have significant importance for the successful treatment of chronic venous diseases. This ensures spreading of exudates to a larger area and, therefore helps in faster evaporation. It prevents the excess moisture build-up and protects skin from maceration. In this research work, we examined the liquid transport performance of different wadding using a prototype. The above apparatus was especially designed to pour the liquid at the center of a circular specimen in a controlled fashion, and simultaneously observed the nature of liquid transport every second. Several parameters such as the anisotropic nature of liquid spreading, the extent and rate of liquid transport in several directions, the area of wet surface with time, etc., were obtained for the evaluation.

Figure 2 shows the liquid transport behavior of a wadding sample (sample code A11). The anisotropic nature of liquid spreading can be easily observed from Fig. 2(a), which shows the liquid movement along eight different directions (D1-D8) from the center of the circular specimen. The extent of liquid movement in a particular direction is faster initially, and thereafter the rate slows down. For example, the liquid spreads 8.25 cm along radial direction D3 in the first 1 min, and thereafter it takes more than 10 min to cover remaining distance (2.75 cm) to finally reach to the edge. The kinematics is different for each direction, which is due to the non-uniform capillary network found in the structure of nonwoven. The manufacturing process of a needle-punched nonwoven results in complex orientation of fibres in the structure, and it is highly unlikely that the shape or size of the pores will be same in all directions. The non-uniform spreading of liquid makes it difficult to do a comparative study of different samples along a particular direction. To overcome this problem, the graph of the wet area of the specimen versus time was obtained the following procedure as described in material and method section. Figure 2(b)

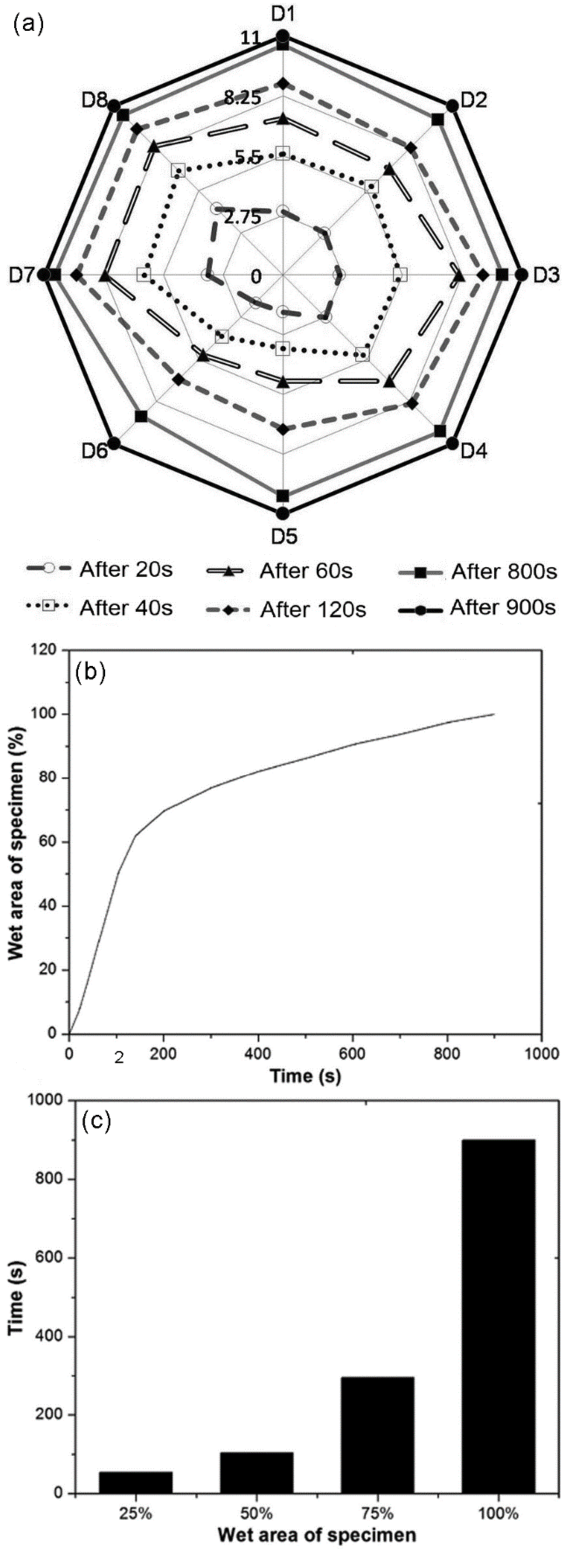

Fig. 2 — Wicking characteristics for a nonwoven specimen (Sample A11; specimen radius = 11 cm) (a) liquid transport in different directions, (b) area of the specimen covered by the liquid over time, and (c) time taken by liquid to cover 25, 50, 75 and 100% area of specimen (coefficient of variation <6%).

shows the area of a specimen covered by the liquid with time. The rate of spreading is more at the beginning, and gradually it decreases over time. During the flow, the liquid spreads and occupies the free space available in the pores of the specimen. In the beginning, the air present in the pores offers little resistance to the flow of liquid discharged at the center of the specimen, and this causes faster spreading. The free space is readily occupied by the liquid, and slowly these capillaries become saturated that offer higher resistance to the liquid movement. The resistance to liquid flow keeps on increasing during the course which continuously decreases the rate of spreading. For easy comparison of wicking in different nonwovens, the time taken by liquid to cover 25, 50, 75 and 100% area of the specimen was used. Figure 2(c) shows the above plot. The lower time taken to cover a particular area indicates faster spreading or higher spreading rate.

3.1 Effect of Needling Density

The performance of wadding having varying needling density was examined. For the comparison, nonwovens having different needling densities (50E4, 130E4, 210E4 punches/m²) were carefully selected keeping levels of other factors, i.e. mass per unit area and fibre denier the same. Figure 3(a) shows the effect of needling density on wicking performance. It is observed that the time taken to wet same area of specimen increases with the increase in the level of needling density ($p < 0.01$). The time taken to wet 100 % area is 696, 775 and 868 seconds respectively for samples having 50E4, 130E4 and 210E4 punches/m². This shows slower spreading rate for higher punch density sample. There exists different pore size distribution, such as small, medium and large diameter pores, for a needle punch nonwoven sample. Generally, larger size pores allow easy flow of liquid through the structure without unnecessary pressure built-up. In a needle punching process, larger pores are converted into medium pores and medium pores are converted to smaller pores due to entanglement of the fibres by the barbed needles[11]. Increase in the needling density leads to more participation of fibre transport through the thickness of web, and results in significant reduction in the number of larger size pores. Therefore, the nonwoven web with higher punch density becomes more compact with more percentage of smaller or medium size pores compared to larger size pores, and offers high resistance for the free movement of fluid through its structure. This results in slower wicking for nonwoven samples with higher punch density.

3.2 Effect of Mass per Unit Area

Figure 3(b) shows the influence of mass per unit area on wicking of nonwovens. It can be observed that the time taken to cover 100 % area for 100, 200 and 300 g/m^2 samples are 548, 680 and 775 seconds respectively. As the mass per unit area increases, there are more number of fibres present for the punching process in the same area[10]. This promotes more entanglement of fibres in the web, causing more closing of free space in the structure with the production of more number of capillaries with a smaller average diameter. This offers high resistance for the free movement of liquid through the structure, and therefore stimulates slower spreading rate for higher mass per unit area ($p < 0.01$).

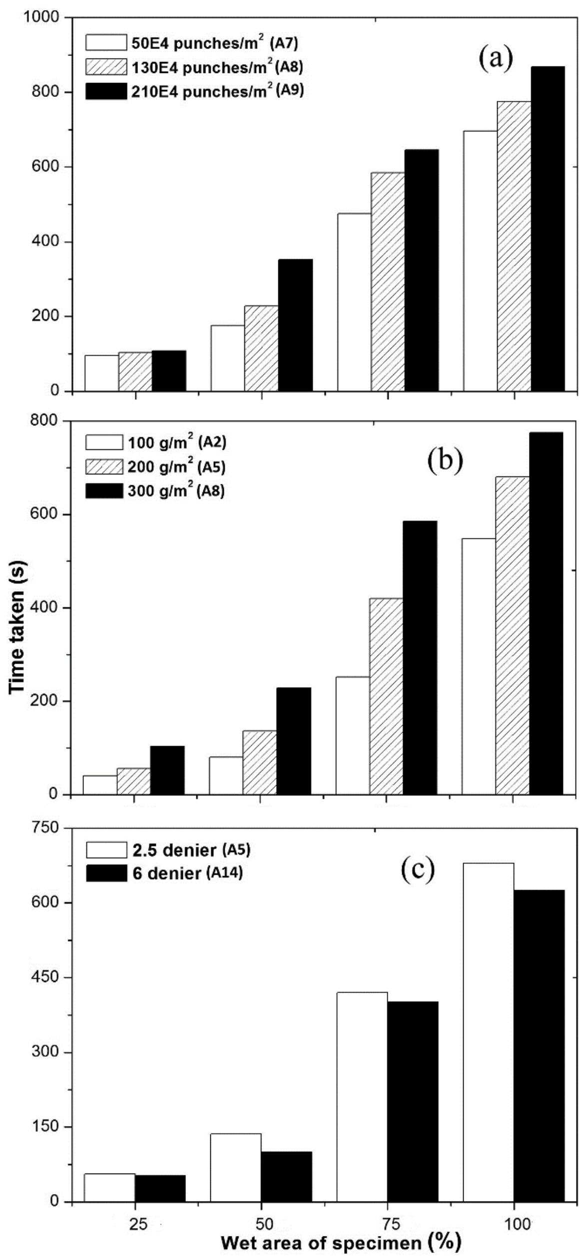

Fig. 3 — Effect of structural parameters of the nonwoven on wicking (a) effect of needling density, (b) effect of mass per unit area, and (c) effect of fibre denier [liquid discharge rate = 7.5 mL/min] (3%<CV<8%)

3.3 Effect of Fibre Linear Density

Wicking performance of nonwoven made from PP fibres with different linear densities (2.5 and 6 denier) was examined. Figure 3(c) shows the effect of fibre denier on liquid transport. It can be seen that nonwoven made of coarser fibres (6 denier) shows faster spreading compared to finer fibres (2.5 denier) ($p < 0.01$). Sample made of coarser fibres takes less time to wet the same area than the sample made of finer fibres. The time taken to cover 100 % area for 6 and 2.5 denier samples are 625 and 680s respectively. The reason for this difference is the high porosity in case of coarser fibres. For the same mass per unit area, more number of fibres will be available for punching process for the finer fibre as compared to coarser fibre. This will generate more contact points and finally higher number of smaller capillaries for lower fibre denier, and therefore, slower spreading rate.

3.4 Effect of Normal Pressure

Liquid transport behavior under confinement is critical for wadding. Wadding is always used underneath as a compression bandage, which applies a significant amount of transverse pressure (20-60 mmHg) on wadding. Under external pressure, the porous network of wadding is changed to a greater extent; this may results in different liquid transport behavior[18]. We also analyzed the effect of different transverse pressures on the wicking performance of nonwovens. Different transverse pressure in the testing specimen was generated by the application of dead weights over the upper disc as described in Materials and Methods section. Figure 4(a) shows the wicking behavior of a specimen at four different levels of normal pressure (0.2, 0.8, 1.5 and 2.0 kPa). It is observed that the spreading rate slows down with the application of transverse pressure ($p < 0.01$). The time taken to cover 100% area of the specimen is 420, 480, 620 and 780 s respectively for 0.2, 0.8, 1.5 and 2 kPa pressure levels. Increasing normal pressure on a nonwoven impedes the capillaries, decreases the pores size, and finally reduces the porosity of the fibrous structure significantly. This causes more drag or resistance to the liquid transport through the network, and hence slower wicking rate.

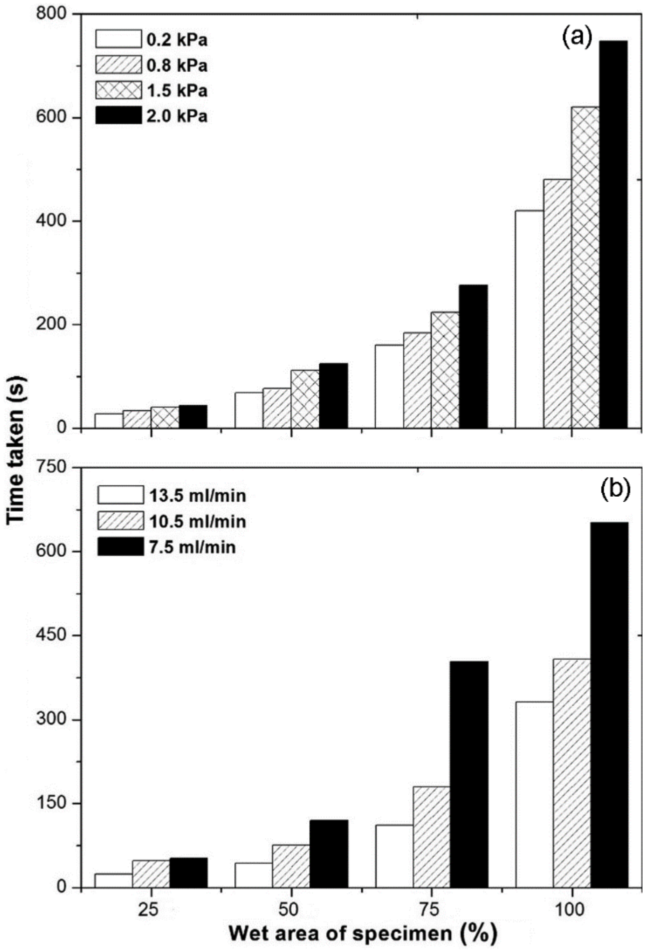

Fig. 4 — (a) Effect of transverse loading on the wicking of a nonwoven (CV<5%) (sample code A10), (b) effect of liquid discharged rate on the wicking of a nonwoven (CV<6%) (sample code A4)

3.5 Effect of Liquid Discharge Rate

The discharge rate or the generated amount of body fluids or exudates is highly variable in different patients. It is highly expected that some patients may generate higher amount of exudates that may depends on the area of the wounded region. Furthermore, the amount of sweating for different wounded patients is variable which depends on the temperature of skin and its pore size. In the view of above facts, we analyzed the spreading behavior at different levels of liquid discharge rate. Three different levels of rate (13.5, 10.5 and 7.5 mL/min) were set using IV-drip system attached to the flow tube as described above. Figure 4(b) shows the results of wicking at different discharge rates. The time taken to cover 100% area is found 332, 408 and 653s respectively for 13.5, 10.5 and 7.5 mL/min discharge rates. Pouring more amounts of liquid causes faster movement of liquid in the fibrous network, and this stimulates faster spreading. As more volume of liquid enters into the capillary then capillary channel forces this liquid to spread quickly towards the edge of the specimen.

3.6 Selection Criteria for Ideal Wadding

Based on the above facts, it is recommended that wadding samples with more porosity, and larger pore size could help in better management of liquid exudates. Wadding with low mass per unit area and needling density results in more porosity and therefore, can help in faster transport of fluids to a larger area. This will accelerate the evaporation and thereby prevent excess moisture build-up. Moreover, fibres with higher linear density should be selected for the preparation of wadding to get bigger pore size that is more suitable for faster spreading.

4 Conclusion

The study shows that spreading of liquid depends significantly on many variables such as fibre linear density, mass per unit area, needle density, etc. The spreading rate is higher for the samples having more free spaces in the capillary network. Increasing mass per unit area and needling density reduces the porosity, and stimulates lower rate. Nonwoven made from coarser fibres results in larger capillaries and shows faster spreading. The porosity of nonwoven is reduced by normal pressure, and therefore, the application of higher pressure slows the spreading. To obtain better fluid transport, it is recommended to use a wadding structure having higher porosity and bigger pore size.

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References

1 Hegarty-Craver M, Grant E, Kravitz S, Reid L, Kwon K & Oxhenham W, *J Wound Care*, 23(9) (2014) S14.
2 Kumar B, Das A & Alagirusamy R, *Phlebology*, 29(6) (2013) 376.
3 Moffatt C J, Mccullagh L, O'connor T, Doherty D C, Hourican C, Stevens J, Mole T & Franks P J, *Wound Repair Regen*, 11(3) (2003) 166.
4 Kumar B, Singh J, Das A & Alagirusamy R, *Material Science Eng - C*, 57 (2015) 215.
5 Anand S & Rajendran S, Effect of fibre type and structure in designing orthopaedic wadding for the treatment of venous leg ulcers, in *Medical Textiles* and *Biomaterials for Healthcare*, edited by C A Subhash and J F Kennedy, (Woodland Publishing Limited) 2006, 243.

6 Moffatt C, *Int J Low Extrem Wounds*, 1(1) (2002) 13.
7 Dale J J, Ruckley C V, Gibson B, Brown D, Lee A J & Prescott R J, *Eur J Vasc Endovasc Surg*, 27(1) (2004) 94.
8 Fauland G, Lenz A, Rohrer C & Bechtold T, *Text Res J*, 83(8) (2012) 871.
9 Cutting K F & White R J, *Professional Nurse*, 18(1) (2002) 33.
10 Midha V K & Mukhopadyay A, *Indian J Fibre Text Res*, 30(2) (2005) 218.
11 Maity S & Singha K, *Frontiers Sci*, 2(6) (2012) 226.
12 Kumar B & Das A, *Fibers Polym*, 15(3) (2014) 625.
13 Kumar B, Das A, Alagirusamy R, Singh J, Garg V, & Gupta R, *Fibers Polym*, 15(12) (2014) 2665.
14 Babu V R, Koushik C V, Lakshmikantha C B & Subramaniam V, *Indian J Fibre Text Res*, 36(1) (2011) 99.
15 Rossi R M, Stämpfli R, Psikuta A, Rechsteiner I & Brühwiler P A, *Text Res J*, 81(15) (2011) 1549.
16 Kumar B & Das A, *J Text Inst*, 105(8) (2014) 850.
17 Patnaik A, Rengasamy R S, Kothari V K & Ghosh A, *Text Prog*, 38(1) (2006) 1.
18 Kumar B, Das A, Pan N, Alagirusamy R, Gupta R & Singh J, *J Biomater Appl*, 30 (5) (2015) 589.