National Defence / Défense nationale

# THE VERTICAL AND HORIZONTAL WICKING OF WATER IN FABRICS (U)

by

Rita M. Crow and Malcolm M. Dewar



## DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL NOTE 93-3

Canada



January 1993
Ottawa

National Defence / Défense nationale

# THE VERTICAL AND HORIZONTAL WICKING OF WATER IN FABRICS (U)

by

**Rita M. Crow and Malcolm M. Dewar**
*Environmental Protection Section*
*Protective Sciences Division*

**DEFENCE RESEARCH ESTABLISHMENT OTTAWA**
TECHNICAL NOTE 93-3

PCN
051LC

January 1993
Ottawa

## ABSTRACT

This paper examines the vertical and horizontal wicking or movement of water along a strip of textile material, a common method of evaluating the wicking behaviour of fabrics. It was found that the fabrics of this study contain imperfect capillaries, with no one property, other than gross surface characteristics, universally contributing to their wicking behaviour. It was concluded that the wicking behaviour of each fabric must be determined individually.

## RÉSUMÉ

Ce rapport décrit l'examen de l'effet mèche vertical et longitudinal de l'eau d'une lisière de tissu. Il s'agit d'une méthode commune pour l'évaluation du comportement de l'effet mèche des tissus. Cette étude nous a permis de découvrir que les tissus analysés contiennent des capillaires imparfaits. Aucune propriété physique ne contribue au comportement de l'effet de mèche des tissus, à l'exeption des caractéristiques de la surface brute. Nous avons conclu que le comportement de l'effet mèche de chaque tissu doit être déterminé individuellement.

## EXECUTIVE SUMMARY

The movement or wicking of water in fabrics is of current interest because of the recent introduction of fibres, yarns and fabrics which manufacturers claim impart great personal comfort to the wearer. This comfort is said to be due to the fibre, yarn or fabric's ability to wick perspiration away from the skin, leaving the wearer dry and warm. As part of an on-going study on the movement of water in and through textile materials, this paper examines the vertical and horizontal wicking of water along a strip of textile material, a common method of evaluating the wicking behaviour of fabrics.

Seven fabrics of varying fibre content and physical properties were examined. The majority of the fabrics wicked similarly to theoretical capillaries, with the water moving quickly along the fabric and then slowing up with time. This was the case whether gravity was involved or not, i.e. whether the sample was vertical or horizontal. However, only in two tests did the fabrics wick according to the classical equation for liquid movement in capillaries. It was concluded that textile fabrics contain imperfect capillaries, with no one property, other than gross surface characteristics such as "troughs" on the surface, universally contributing to their wicking behaviour. Therefore, the wicking behaviour of each fabric must be determined individually, rather than being predicted from the classical wicking equation.

## INTRODUCTION

The movement of liquids in fabrics by wicking (as opposed to by pressure) is of current interest because of the recent introduction of fibres, yarns and fabrics which manufacturers claim impart great personal comfort to the wearer. This comfort is said to be due to the fibre, yarn or fabric's ability to wick perspiration away from the skin, leaving the wearer dry and warm. As part of an on-going study on the movement of water in and through textile materials (1,2,3), this paper examines a common method of comparing the wicking behaviour of fabrics, namely, the vertical and horizontal wicking of water along a strip of textile material. It is noted that this method may be more applicable to materials in heat pipes or kerosene lanterns than to clothing.

### Review of Literature

Harnett and Mehta (4) compared various laboratory test methods for measuring wicking. They concluded that measuring the wicking heights in various fabrics only gives some indication of the rate of advance of the liquid front and would be more valuable if linked with mass transfer rates.

Minor and Schwartz (5) give the equation for the rate at which a liquid front advances in a fabric where the effect of gravity is negligible as

$$s = kt^{1/2}$$

where s is the distance travelled, t the time and k the constant characteristic of the yarn-liquid system. The plot of this equation is shown in Figure 1. They theorized that high twist yarns or plied yarns should wick water further along the fabric.

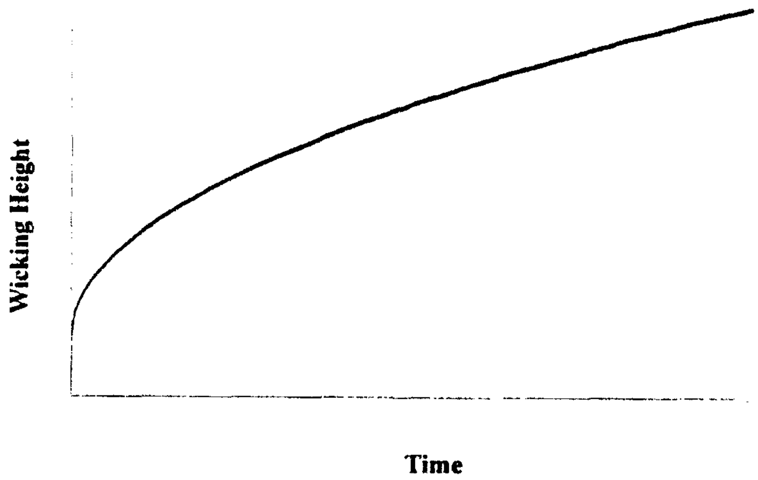


**Figure 1.** Theoretical wicking behaviour in capillaries.

Hollies et al (5) studied the capillary transport in yarns and found that it followed the above classical relationship for nylon yarns which varied in twist, number of fibres and mean capillary radius. They then took yarns taken from nylon, wool and wool blended serge fabrics and varied their twists. They found that at low (20 twists/10 cm) and high (120 twists/10 cm) yarn twists, the water transport rate was lower than at the intermediate values (40 twists/10 cm). At the lower twists, they concluded this was caused by a substantial reduction in number and continuity of interfibre capillaries. At the higher twists, the capillary spaces between the yarns would approach zero, thus retarding the flow of water along the yarn.

In Part II of their paper (6), they examined the horizontal wicking characteristics of a range of fabrics. They found that the amount of water transported by a fabric depends on its water-holding capacity and on the rate with which the water travels through the fabric. They again found that there is a linear relationship between the square of the distance travelled and time. They also found that not all of their curves passed through the origin. They measured the water transport in yarns taken from the fabric and found the wicking behaviour to be similar. They concluded that the effects of change in yarn twist, fibre denier and yarn size would also be evident in the water transport rates of the fabrics. They found that the wool blends tended to have lower water transport rates than fabrics of all synthetic or cotton content. They attributed this to the random arrangement of the wool fibres in the yarns. In a second series, they compared the wicking of acrylic/wool blends and could not predict the wicking properties. They concluded that this was due to the fibre randomness.

**Method**

To measure the vertical and horizontal wicking of the fabrics, a sample holder was made consisting of a row of common household pins mounted at intervals of 0.25 cm in a strip of 0.3 cm thick plexiglass so that their points protrude about 0.5 cm. Each pin was connected to a computer-controlled data acquisition relay assembly. The resistance between the first or common pin and each of the other pins were measured and recorded by the computer at a preset sampling rate. When the wicking water reached any pin beyond the common pin, this event was marked by an abrupt drop in resistance. The number of pins monitored and the sampling rate could be varied to match the wicking properties of the fabric. For faster wicking fabrics, more pins were monitored and the sampling rate increased. Typically, 12 to 15 pins were monitored at rates from 1 to 120 pins per minute. The experiment was terminated when the water had wicked along the sample about 25 to 40 mm or after about 25 minutes, whichever happened first.

Prior to the experiments, the samples were conditioned for at least 24h in a room having the atmosphere controlled at 20°C and 65% relative humidity (R.H.). The experiments were also done in this room. A fabric sample, 2.5 cm wide and 10 cm long was mounted on the sample holder so that the pins penetrated the sample on its centre line. Care was taken to make sure the sample did not touch the plexiglass. Relative positions were adjusted so that 1 cm of the sample was immersed in distilled water and the water level was at the common pin. The computer was activated as the water started to wick up or along the fabric strip.

The horizontal wicking experiments were done in similar fashion with the sample holder rotated to a horizontal attitude. It was sometimes necessary to direct the lower end of the sample into the water by means of a rubber band around the end of the plexiglass and over the sample.

The fabrics used were from Testfabrics Incorporated, New Jersey, U.S.A. and their pertinent physical properties are given in Tables 1a and 1b. The "warp" and "weft" yarn properties of nylon knit are not included in Table 1b because the "warp" and "weft" yarns in knits are one in the same. The fabrics were selected mainly because they wicked at reasonable rates and in such quantities that there was sufficient water to short circuit the pins and thus give a reading. Experiments were done in both the warp and weft directions.

**Table 1a.** Pertinent Physical Properties of the Fabrics

| Fibre | Weave | Yarn | Thickness mm | Mass ($g/m^2$) | Count Yarns/cm |
|---|---|---|---|---|---|
| Nylon Knit | double knit | cf* | 1.02 | 215 | 12x16 |
| Wool Challis | plain | staple | 0.46 | 124 | 22x28 |
| Silk Broadcloth | plain | cf | 0.15 | 60 | 42x34 |
| Silk Noil | plain | cf, slubs | 0.58 | 144 | 21x20 |
| Linen | plain | staple | 0.20 | 89 | 22x18 |
| Linen, Heavy | plain | staple | 0.38 | 223 | 14x15 |
| Cotton, Lightweight | plain | staple | 0.41 | 155 | 22x17 |
| Cotton Duck | plain | staple | 0.58 | 328 | 21x17 |

* continuous filament

**Table 1b.** Pertinent Physical Properties of the Fabrics Continued

| Fabric Description | % Water in Warp Yarns | % Water in Weft Yarns | Twist of Warp Yarns per 10 cm | Twist of Weft Yarns per 10 cm |
|---|---|---|---|---|
| Wool Challis | 106 | 107 | 71 2-ply<br>30 | 45 |
| Silk Broadcloth | 138 | 167 | 65 2-ply<br>31 | 55 |
| Silk Noil | 200 | 283 | 57 | 60 |
| Linen | 125 | 83 | 41 | 46 |
| Linen Heavy | 96 | 109 | 36 | 32 |
| Cotton, Lightweight | 173 | 143 | 45 | 58 |
| Cotton Duck | 159 | 193 | 46 2-ply<br>35 | 46 2-ply<br>52 |

To confirm the precision of the experimental procedure, the water was coloured with red ink and several experiments were done as described above while the advance of the water front was simultaneously recorded and observed visually. The correlation of the two sets of data was extremely good.

In order to determine the reproducibility of the method, the experiments on several fabrics were carried out on four occasions. Typical results are shown in Figure 2.

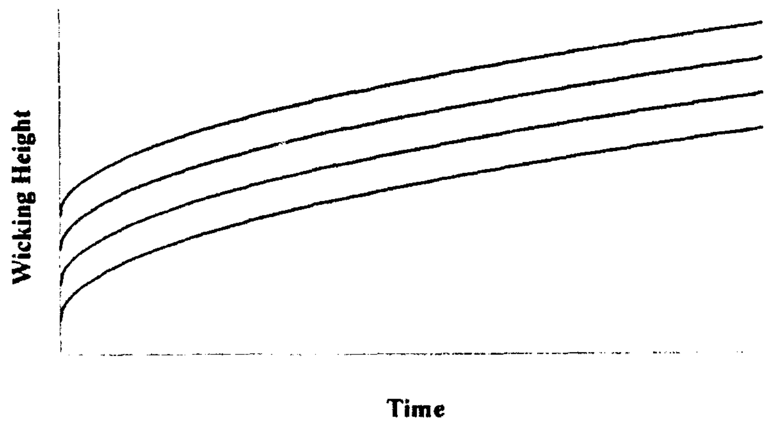


**Figure 2.** Typical Wicking Results

The basic shape of the wicking curves is the same, only the placement on the Y-axis differs. This is considered to be due to the variability in the specimen's readiness to start to wick or the "priming" factor. This variability is probably due to uneven finishing of the fabric. This result duplicates Hollies results (7) in which his plots of distance versus the square of time did not pass through zero. Because of the excellent reproducibility in our the wicking experiments when the priming factor is eliminated, only one test was done for each fabric.

## Experimental Limitations

The experiment is limited by the operating characteristics of the apparatus. For instance, the fabrics were selected because they held sufficient water to cause a short circuit between the common pin and each successive pin. With the exception of the nylon double knit, the fabrics which were selected with this characteristic were made from natural fibres which tend to have thicker yarns. Further, the data acquisition system was such that only a finite number of readings could be made during any experimental run. If the fabric wicked very quickly, many readings per unit time were made and so the experiment would have to be terminated, say, after 100s. This contrasted with experiments in which the fabric wicked very slowly, and were stopped after about 1500s. This was done because it was thought that evaporation of water from the wicking sample would introduce an error into the results.

## Experimental Results and Discussion

The experimental results of the vertical and horizontal wicking for both the warp and weft directions are shown in Figures 3 through 10.

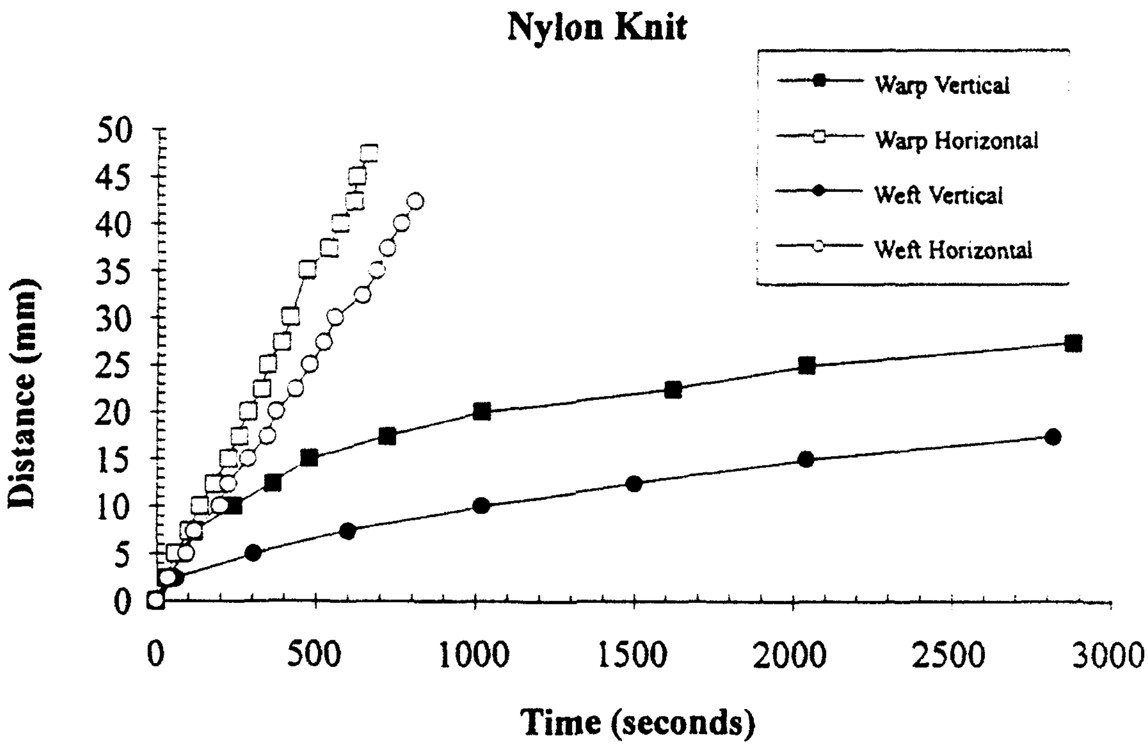


Figure 3. The Wicking Behaviour of Nylon Knit

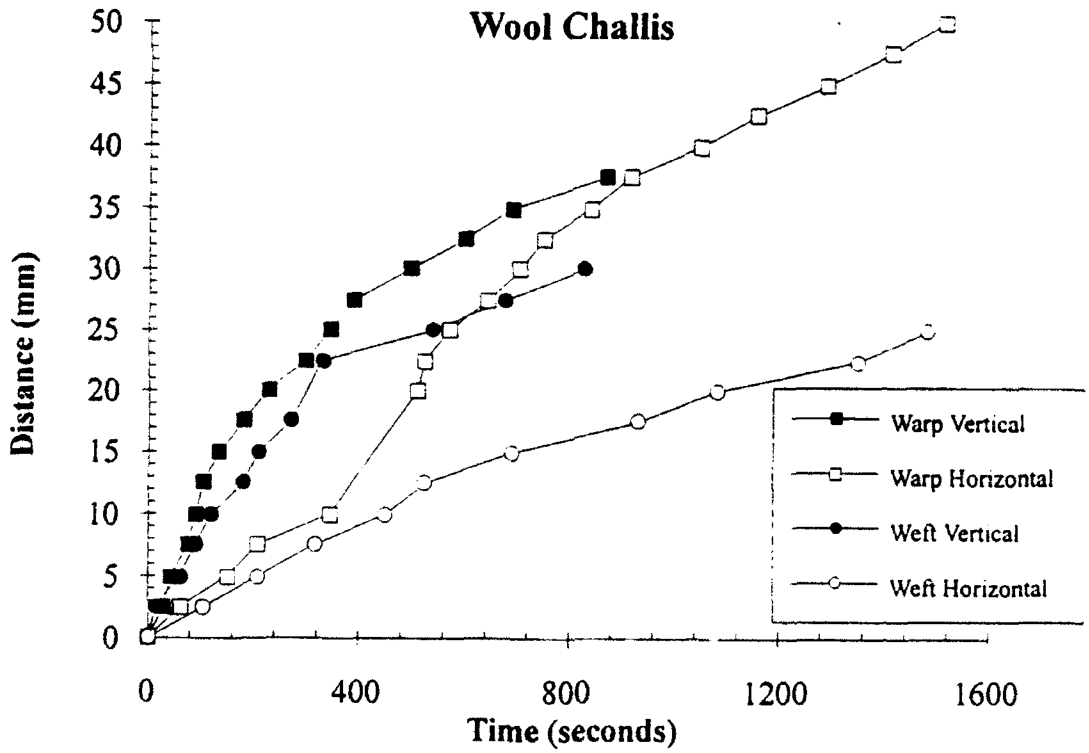


Figure 4. The Wicking Behaviour of Wool Challis

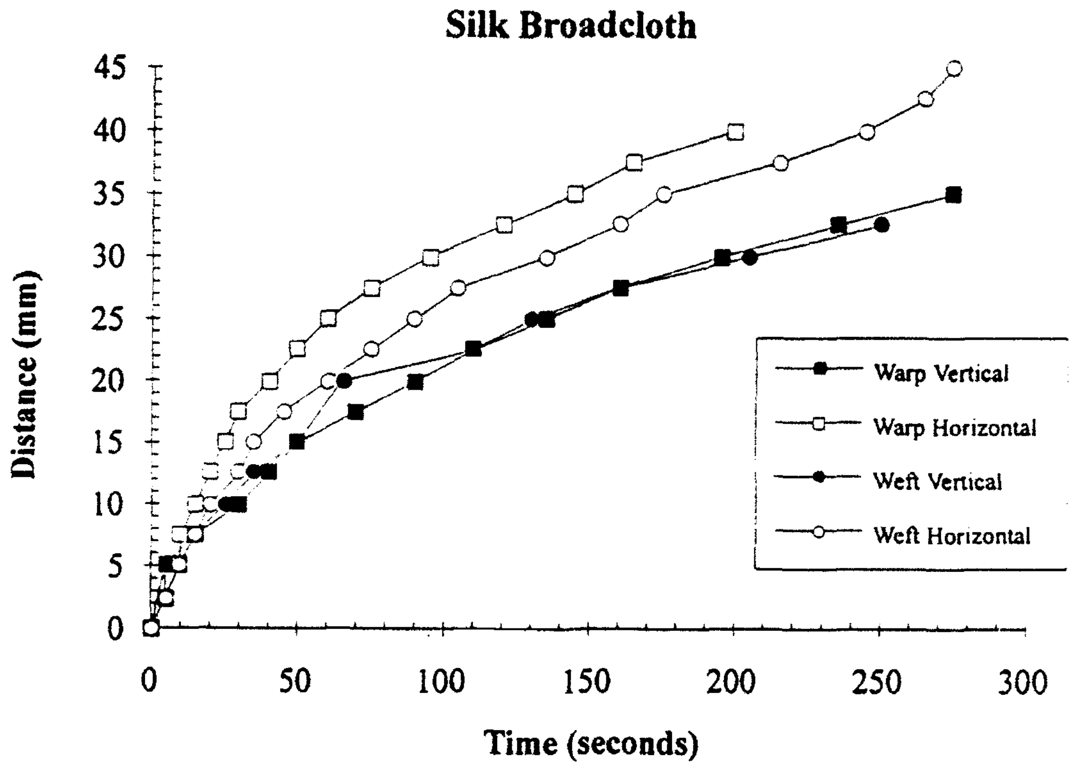


Figure 5. The Wicking Behaviour of Silk Broadcloth

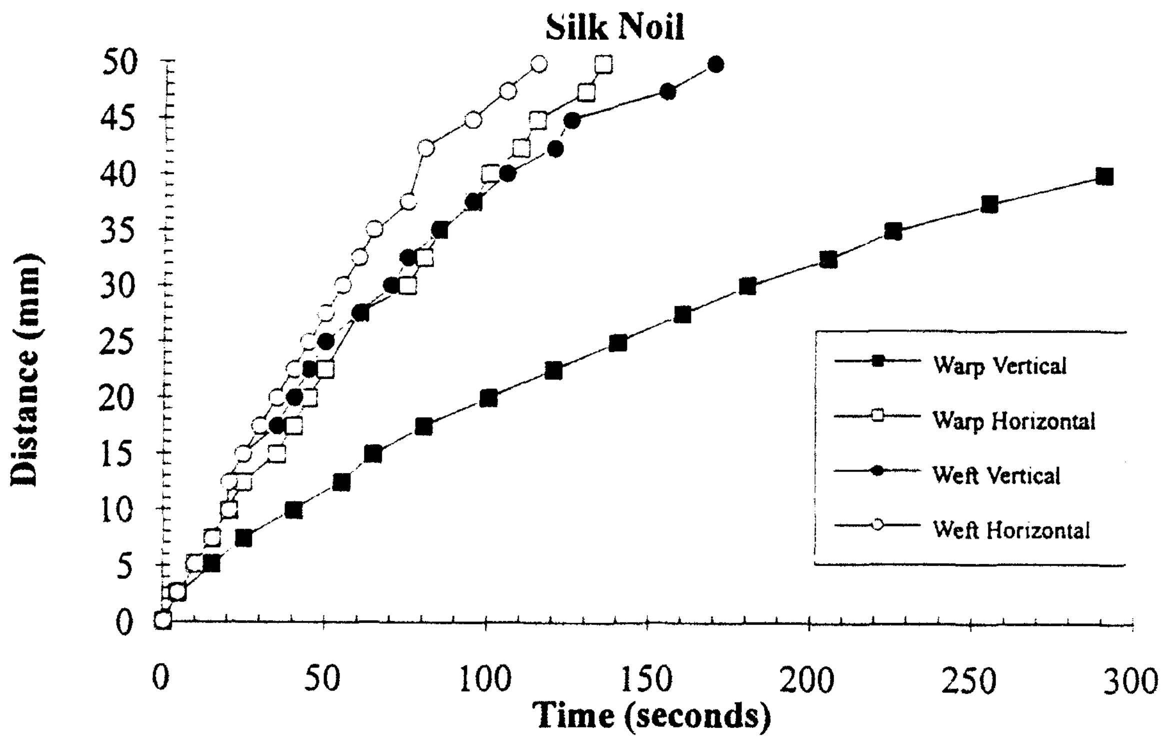


Figure 6. The Wicking Behaviour of Silk Noil

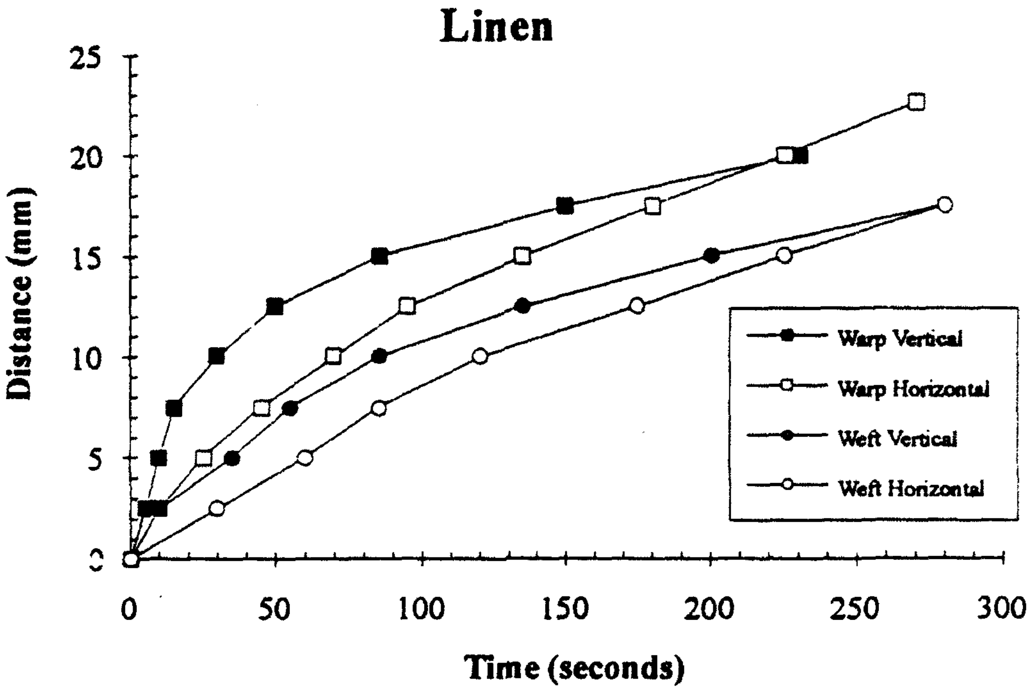


Figure 7. The Wicking Behaviour of Linen

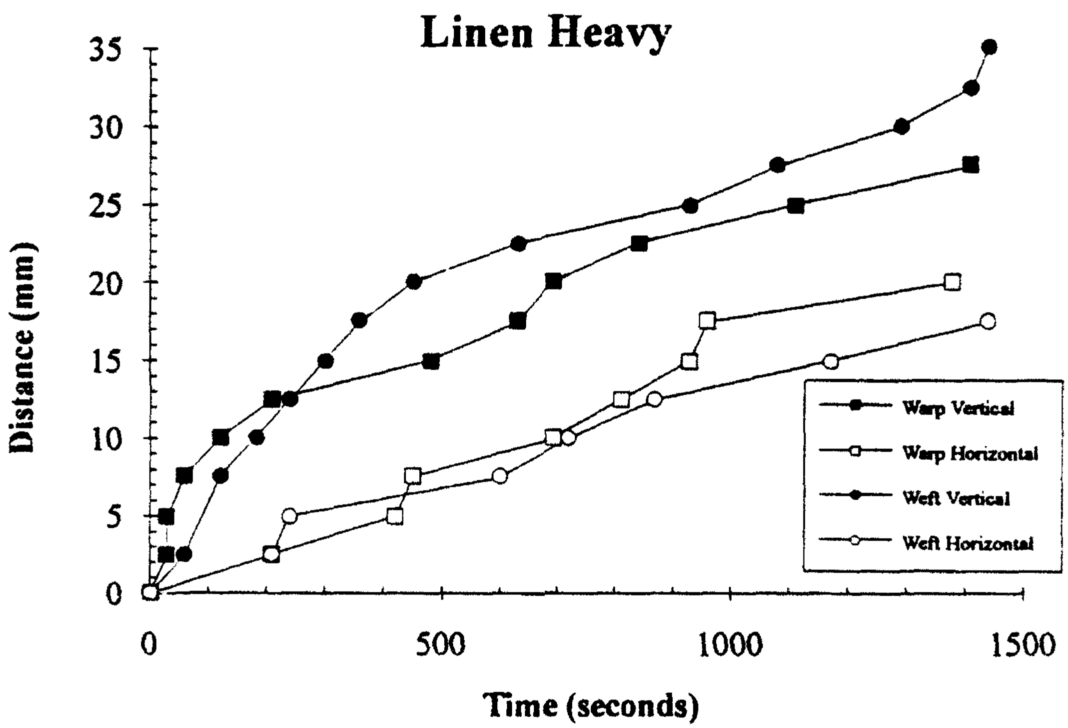


Figure 8. The Wicking Behaviour of Linen Heavy

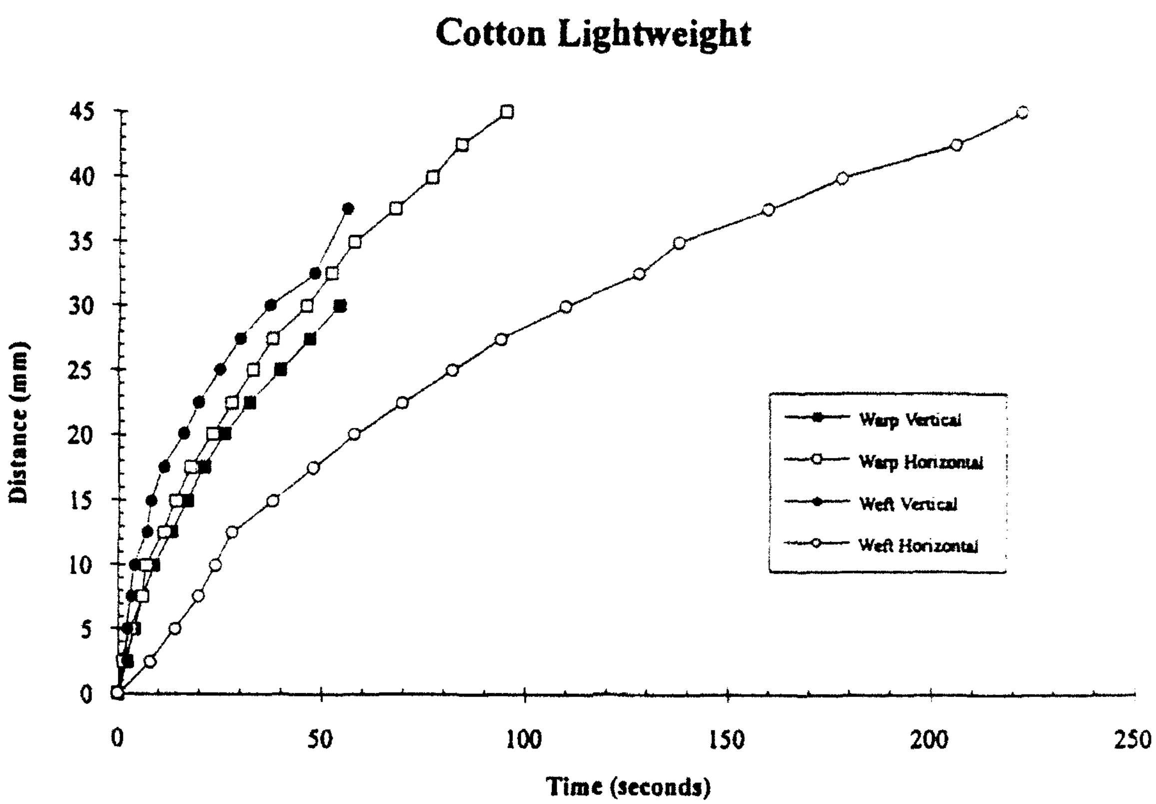


Figure 9. The Wicking Behaviour of Cotton Lightweight

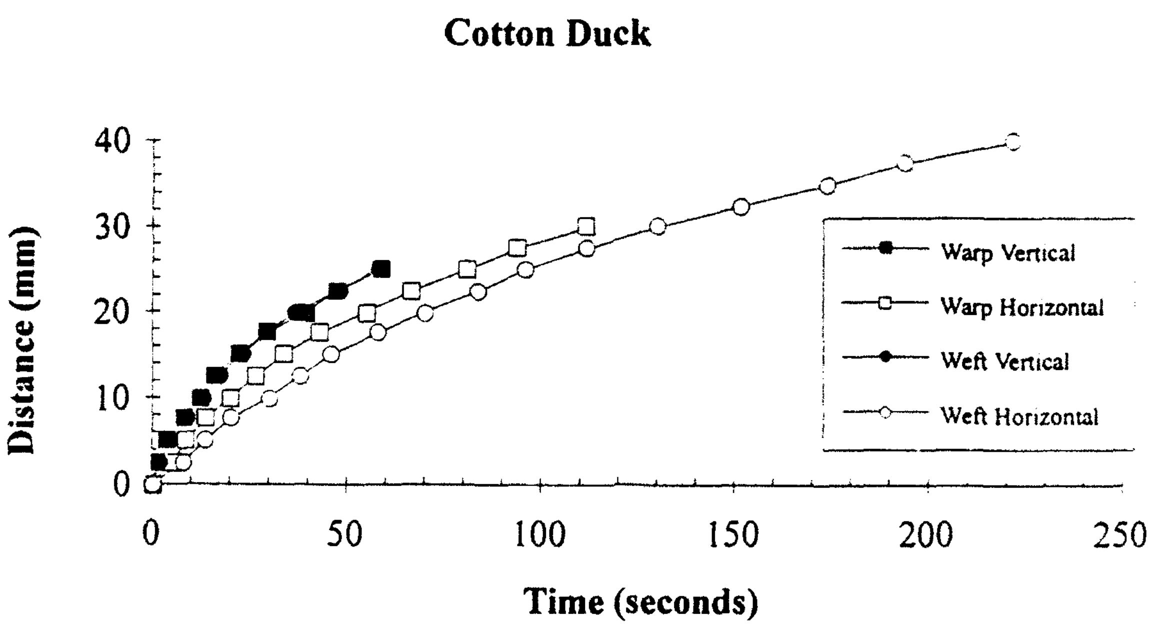


Figure 10. The Wicking Behaviour of Cotton Duck

The graphs show that the majority of the fabrics wicked similarly to theoretical capillaries, with the water moving quickly along the fabric and then slowing up with time. There were some fabrics for which the wicking was at a constant rate, and within the constraints of this experiment, wicking had not yet started to slow with time. This mainly occurred in the horizontal direction.

**Table 3.** Summary of Wicking Results

| Fabric | Wicking Behaviour During Experiment | Distinctive Characteristic |
|---|---|---|
| Nylon Knit | Horizontal faster and farther | Cross-sectional troughs |
| Silk Broadcloth | Horizontal faster and farther | 42x34 count<br>2-ply warp yarn |
| Linen,Heavy | Vertical faster and higher | None |
| Linen | Warp faster and higher | More water in warp yarns |
| Wool Challis | Weft horizontal slower and shorter | 2-ply warp yarns |
| Cotton, Lightweight | Weft horizontal slower | Higher twist weft yarns |
| Silk Noil | Warp vertical slower and lower | More water in weft yarns |
| Cotton Duck | All similar | Higher twist ply yarns in weft<br>More water in weft |

The above Table shows that this group of fabrics did not wick in a consistent, similar manner. When lines of best fit for each curve was determined, only the silk broadcloth, weft vertical and the nylon double knit, weft vertical gave the classic $s = kt^{1/2}$ equation.

However, in a couple of instances, a unique physical property of a fabric can explain its wicking behaviour. For instance, the nylon double knit wicked quicker horizontally than vertically in both the warp and weft directions. Examination of this double knit showed that it has distinct paths or troughs on its surface. Thus when it was in the horizontal position, the water ran in these troughs, as well as wicking along the yarns.

No explanation could be found for why the silk broadcloth wicked more quickly in the horizontal than in the vertical position. From its distinctive characteristics, one would have thought that there would have been a difference between the warp and weft rather than between vertical and horizontal. Likewise, the heavy linen had no distinctive characteristics which would indicate why it wicked more quickly in the vertical rather than the horizontal direction.

An explanation can be given for the lightweight linen which wicked higher and faster in the warp than in the weft direction. The warp yarns absorbed considerably more water than the weft yarns (103% versus 83%) . In the experiments with the dye and the woven fabrics, it was observed that there were usually two "fronts" which moved up the strip of fabric. The first front was the water going up the yarns which had one end immersed in the beaker of water and the second front was the water wicking from these yarns to and along the cross yarns. Thus the rate of wicking depended on two factors, the rate at which water was drawn up the yarns which had their ends in the water and the rate at which water was "bled" off these yarns to fill the cross yarns. As a corollary to latter statement, the rate of wicking up the yarns depended on how much water had to be bled into the cross yarns to fill them to capacity. Thus as the water moved up the linen in the weft direction, considerable amounts of water were bled off to fill up the warp yarns, slowing the wicking rate in the weft direction.

Not supporting the above explanation are the silk noil and the cotton duck which should have wicked more quickly in the weft direction since their weft yarns held more water than the warp yarns.

As detailed in the literature review, plied yarns and yarns of intermediate twist should wick water higher. This is not borne out by the inconsistent behaviour of the wool challis, the lightweight cotton and the cotton duck which have either plied yarns or yarns of distinctly differing twists.

## Conclusion

Textiles fabrics contain imperfect capillaries, with no one property, other than gross surface characteristics such as the troughs on the surface of the double knit, universally contributing to their wicking behaviour. Therefore, the wicking behaviour of each fabric must be determined individually.

**References**

1. R.M. Crow. Moisture, Liquids and Textiles. DREO Report 920, 1987.

2. R.M. Crow and M.M. Dewar. Liquid transport Across Fabric Layers. DREO Report 1002, 1989.

3. R.M. Crow and M.M. Dewar. The Movement of Liquid in Textiles. 15th Commonwealth Defence Conference on Operational Clothing and Combat Equipment, Canada, 1989.

4. F.W. Minor, A.M. Schwartz, E.A. Wulkow and L.C. Buckles. The Migration of Liquids in Textile Assemblies, Part II: The Wicking of Liquids in Yarns. Text. Res. J. **29**, 12, pp 931-939, 1959.

5. N.R.S. Hollies, M.M. Kaessinger and H. Bogarty. Water Transport Mechanisms in Textile Materials. Part I: The Role of Yarn Roughness in Capillary-Type Penetration. Text Res. J., **26**, 11, pp 829-835, 1957.

6. N.R.S. Hollies, M.M. Kaessinger, B.S. Watson and H. Bogarty. Water Transport Mechanisms in Textile Materials. Part II: Capillary-Type Penetration in Yarns and Fabrics. Text Res. J., **27**, 1, pp 8-13, 1957.

# DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

| | |
|---|---|
| 1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)<br>Department of National Defence<br>Defence Research Establishment Ottawa<br>Shirleys Bay, Ottawa, Ontario K1A OK2 | 2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable)<br>UNCLASSIFIED |

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)

The Vertical and Horizontal Wocking of Water in Fabrics (U)

4. AUTHORS (Last name, first name, middle initial)

CROW, Rita M., DEWAR, Malcolm M.

| | | |
|---|---|---|
| 5. DATE OF PUBLICATION (month and year of publication of document)<br>January 1993 | 6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)<br>15 | 6b. NO. OF REFS (total cited in document)<br>6 |

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Note

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)

Department of National Defence
Defence Research Establishment Ottawa, Shirleys Bay, Ottawa, Ont. K1A OK2

| | |
|---|---|
| 9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)<br>051LC | 9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written) |
| 10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)<br>DREO TECHNICAL NOTE 93-3 | 10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor) |

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

( X ) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

13. **ABSTRACT** ( a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both offical languages unless the text is bilingual).

This paper examines the vertical and horizontal wicking movement of water along a strip of textile material, a common method of evaluating the wicking behaviour of fabrics. It was found that the fabrics of this study contain imperfect capillaries, with no one property, other than gross surface characteristics, universally contributing to their wicking behaviour. It was concluded that the wicking behaviour of each fabric must be determined individually.

14. **KEYWORDS, DESCRIPTORS or IDENTIFIERS** (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

wicking
capillary water
fabrics