

# THERMAL BALANCE IMPLICATIONS OF WATER REPELLENT TREATMENTS ON MILITARY UNIFORM FABRICS

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## INTRODUCTION

Several durable water-repellent (DWR) treatments based on nanotechnology approaches were evaluated on fabrics used for the Advanced Combat Uniform (ACU) and the Battle Dress Uniform (BDU). Soldiers' duty and combat uniforms can be made water-resistant and retain the same air permeability and "breathability" properties as the untreated wicking fabric. Several questions arose as a result of this work. What are the physiological implications of changing the BDU fabric from a wicking fabric to a non-wicking fabric? Will the fabric still be comfortable when a soldier is sweating heavily? Will liquid sweat now remain on the skin underneath the fabric, and is this bad or good?

Following a separate field trial using combat uniforms with and without a DWR treatment, it was found that these treatments decreased the comfort of the uniform in hot and humid environments. The differences between the comfort of the standard control uniforms and those treated with the DWR treatments were not due to intrinsic differences in the air permeability or the water vapor diffusion resistance (breathability) of the fabric. The non-wicking behavior of the fabric was responsible for perceived comfort differences, per comments from the field trial, and by subsequent coupled physiological/fabric modeling. This is consistent with previous studies that have examined the effect of water repellent treatments on cotton fabrics [1-3].

## FABRIC PROPERTIES

Three different fabric treatments were selected for application to the Battle Dress Uniform (BDU) fabric, which is a 50% nylon / 50% cotton blend fabric that has been used in the army combat uniform. For proprietary reasons, the treatments are only identified as given as the "Blue (DWR 1)," "Red (DWR 2)," and "Green (DWR 3)." The U.S. Army's chemical protective Battle Dress Overgarment (BDO) uses the BDU fabric treated with an oil and water-repellent finish (Quarapel treatment), and this fabric was used as the "DWR Control" to compare the effectiveness of the three nanotechnology water-repellent treatments. For some of the laboratory tests, a variety of commercial fabrics incorporating various DWR treatments were included to help in the comparison of the performance of the Red, Blue, and Green treatments. The standard comparison fabrics included an expanded polytetrafluoroethylene microporous membrane, the Joint Services Lightweight Integrated Suit Technology (JSLIST) shell fabric with and without the standard Quarapel treatment, JSLIST with a nanotech DWR, and several varieties of commercially-available "soft-shell" fabrics (Schoeller Textiles and Nextec [4]) that incorporate differential wicking and durable water-repellent finishes. Typical water repellency of some of these fabrics is shown in Figure 1(a).

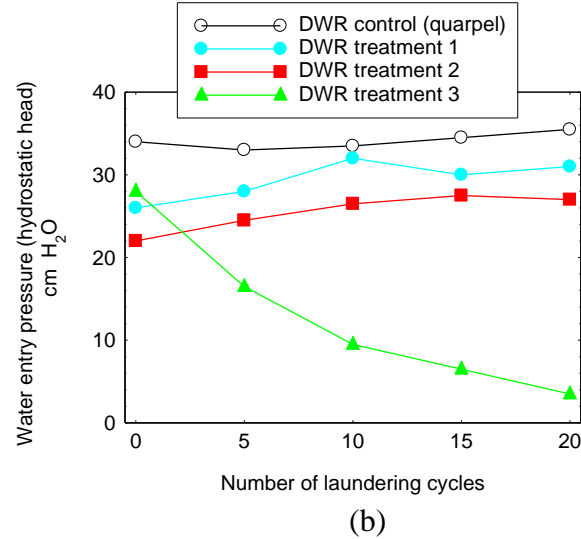
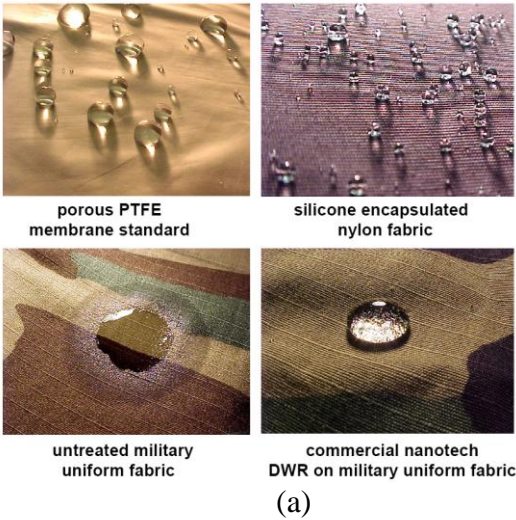


Figure 1. (a) Water droplets on test fabrics. (b) Laundering affects hydrostatic head of four water-repellent fabric treatments. Fabric shrinkage after laundering can increase hydrostatic head due to smaller fabric pores.

Fabric testing included measurements of the relevant transport properties of water vapor diffusion and air permeability, as well as material characteristics such as water entry pressure (resistance to liquid penetration), liquid spray repellency, and fabric pore size [5-8]. Figure 1(b) shows that two of the water-repellent treatments had good durability to laundering (an important issue for soldier duty uniforms). None of the water-repellent treatments significantly affected the breathability, air flow resistance, or pore size of the control fabric. Detailed test results, and information on the experimental methods are available in an open access government technical report [9].

## PHYSIOLOGICAL MODELING

Following the laboratory characterization of the effectiveness of these DWR treatments, a field trial was conducted to determine the usefulness of making soldiers combat and duty uniforms water-repellent. The question of “What are the physiological implications of changing the BDU fabric from a wicking fabric to a non-wicking fabric?” was answered when soldiers found that they disliked the treated uniforms in a hot and humid environment due to the lack of wicking of sweat from their bodies out through the clothing.

A physiological model of an exercising human [10] was combined with a fabric model that accounts for heat transfer, sorption, diffusion, and liquid water transport through the fabric structure [11], for the case of the wicking versus the nonwicking BDU fabric [12].

For the wicking fabric (untreated BDU fabric), the model assumes very high liquid permeability and capillary pressure, which cause any liquid sweat at the skin surface to be quickly distributed within the free porosity of the fabric. This allows comparison of two different clothing materials that are identical in all their properties except that one material will wick sweat away from the skin surface, while the other does not allow wicking through its structure. For the nonwicking case, the liquid sweat remains on the skin, but it is allowed to evaporate based on the local skin temperature, vapor pressure, and local relative humidity gradient.

For the wicking fabric, when liquid sweat is present, wicking effects quickly overwhelm any of the other transport properties (such as diffusion), due to the evaporation of liquid water within the clothing, and the increase in thermal conductivity of the porous textile matrix due to the liquid water that builds up within the clothing layers. An example is shown in Figure 2 for the case of a wicking versus a nonwicking fabric, when a human goes from a light work rate (20 Watt/m<sup>2</sup>) to a heavy work rate (200 Watt/m<sup>2</sup>) for 1 hour, and then back to a light work rate. Environmental conditions in both cases are air temperature of 30°C and relative humidity of 65%. Details of the modeling approach are in reference 12.

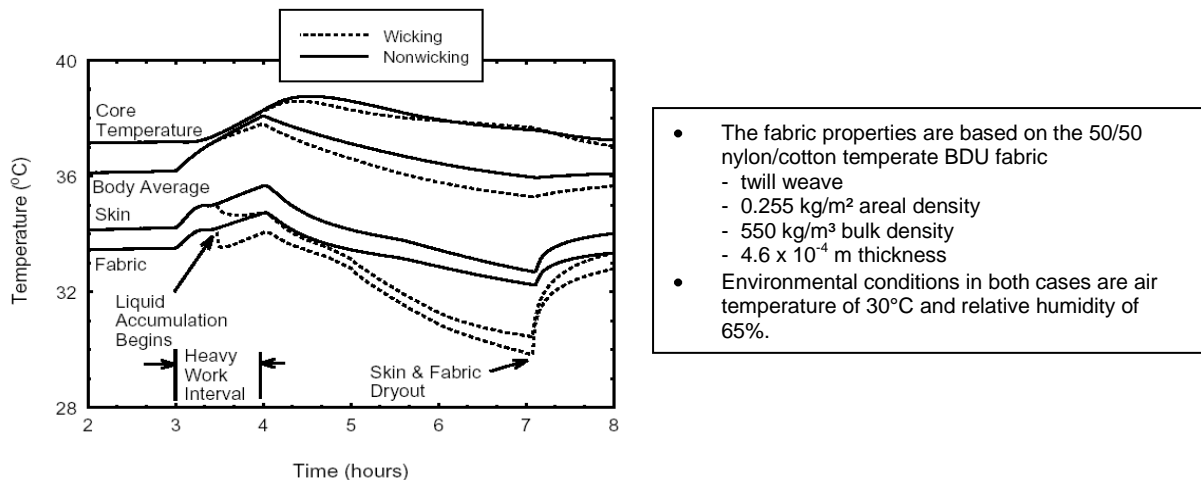


Figure 2. Comparison of a wicking versus a nonwicking fabric (other properties identical) during changes in human work rate.

The model run in Figure 2 shows that there are some differences in the two fabrics, particularly in the skin temperature and in the fabric temperature. The wicking fabric becomes soggy after a while (from the point indicated as “Liquid Accumulation Begins”), and takes some time to dry out. The nonwicking fabric doesn’t soak up water, so the temperatures of the fabric and of the skin remain higher. Perhaps the nonwicking fabric in this case will feel less comfortable, due to the large differences in calculated skin temperatures between the wicking and nonwicking cases. However, the important physiological parameter for heat stress (core temperature) remains nearly identical, indicating little difference in heat strain potential between the two fabrics.

## DIFFERENTIAL TREATMENTS

An additional five finish variations were supplied for the advanced combat uniform (ACU) fabric. One of the DWR treatments allows great flexibility in “tailoring” the treatment to various levels on the outer and inner surfaces of fabrics. The treatments provided a gradation of wicking properties on the inner fabric face, and various levels of water repellency on the outer fabric face. The addition of wicking properties to a water-repellent fabric should provide more comfort in hot and humid environments. These variable treatments helped mitigate the shortcomings of the fabric that was fully treated for water-repellency on both the inner and outer faces. Water drops were applied to either the outer or inner face of fabric (not at the same time). For the inner face, the drop was allowed to spread, and then the wet zone was shown by shining a light through the fabric, as shown in Figure 3. The finish variations examined are listed below in Figure 3(a) alongside the images of the fabrics.

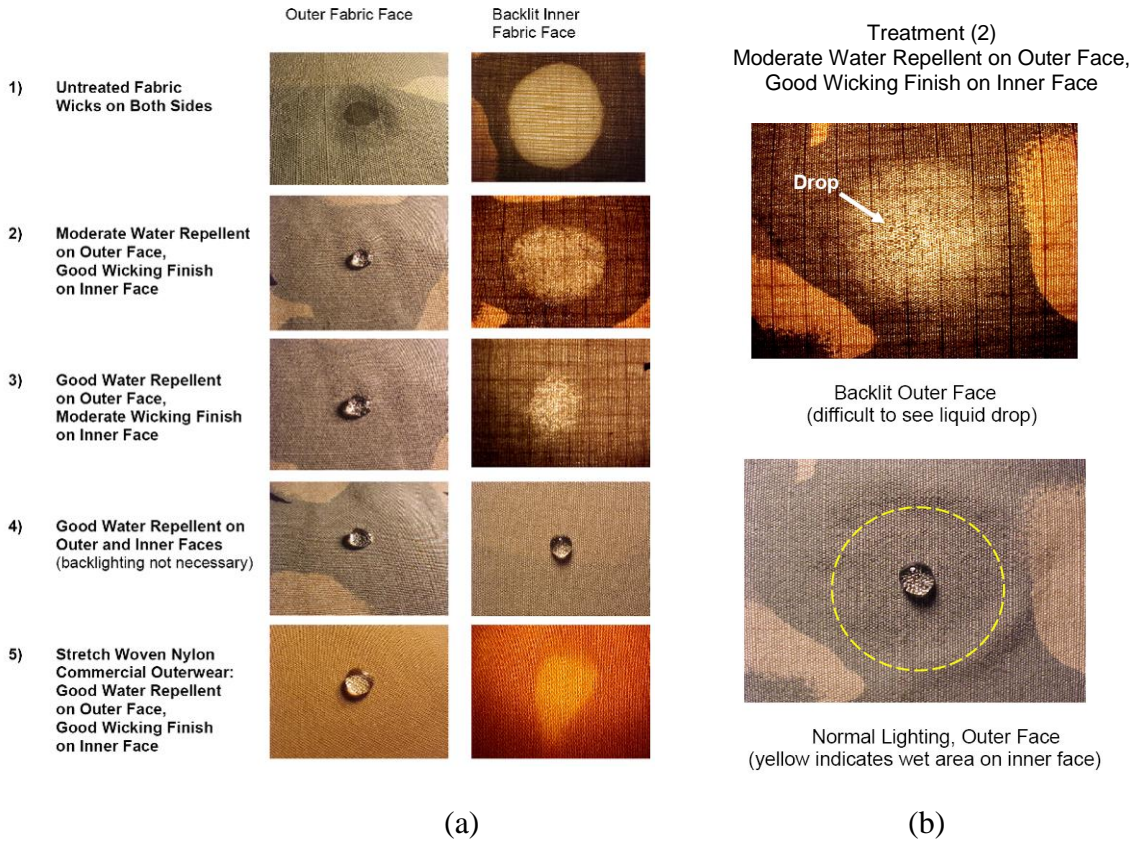


Figure 3. (a) Water drop on inner/outer faces of fabrics with differential treatments. (b) Wet fabric on inside doesn't affect repellency on outside.

The fabrics that have the differential treatments retain their water repellency on the outer face, even if the inner face has a wicking finish and is wet. As shown in Figure 3b, a drop is applied to the inner fabric face and allowed to spread, and then a drop is applied to the outer face. The first picture shows the fabric backlit to show the extent of wicking/spreading on the inner face, and the second picture shows the same fabric with the lighting changed to better show the water droplet on the outer fabric face.

#### *Drying Experiments on Differential DWR Treatments*

Water was applied to the inner surface (body side) of the DWR differential-treated fabrics as shown in Figure 4(a). The fabric was conditioned in a flow cell, and then 0.1 g of water was applied to the surface. Dry air at 30°C flowed past the outer surface of the fabric. A water concentration detector (capacitance-type thin film polymer sensor) monitored the water vapor concentration of the exiting gas stream. The experimental setup was nearly identical to that described in Reference 8. The vapor flux over time was calculated from the gas flow, temperature, and water vapor concentration of the gas stream leaving the test cell.

The drying time and vapor flux are related to spreading of liquid on the surface and through the fabric thickness. As shown in Figure 4(b), the drying time was significantly hindered by the presence of a water repellent finish on the inner surface of the fabric.

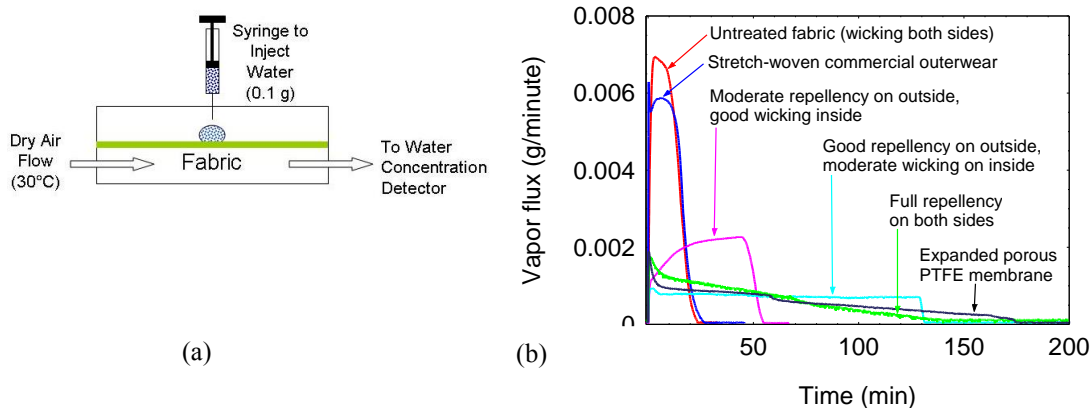


Figure 4. (a) Test configuration for drying experiments. The water was applied to the “body” side or inner face of the fabric that would be oriented to the sweating skin surface in a garment. (b) Drying curves for differential DWR fabric treatments – note superior performance of commercial stretch-woven fabric (Schoeller Dynamic).

## CONCLUSIONS

The standard Battle Dress Uniform (BDU) fabric can be modified with very effective water-repellent treatments. Soldiers’ duty and combat uniforms can be made water-resistant and retain the same air permeability and “breathability” properties as the untreated wicking fabric. Following a separate field trial using combat uniforms with and without a DWR treatment, it was found that these treatments decreased the comfort of the uniform in hot environments. The differences between the comfort of the control uniform and those treated with the DWR treatments are probably not due to intrinsic differences in the air permeability or the water vapor diffusion resistance (breathability) of the fabric. It is more likely that the non-wicking behavior of the fabric was responsible for perceived comfort differences, per comments from the field trial, and by analysis of wicking/comfort properties contained in this report. Some of the DWR treatments are available as coatings on just one side of the fabric. The outer layer of the fabric can be made water-repellent, while the inner surface retains its wicking characteristics. Based on comments from the field trial, and modeling results, such asymmetric treatments would improve the comfort of DWR treatments on military duty uniforms as compared to full water-repellency on both sides of the fabric.

## REFERENCES

- Galbraith, R., Werden, J., Fahnestock, M., Price, B., *Textile Res. J.*, 1962, **32**(3): 236-242.
- Morris, M., Prato, H., Chadwick, S., Bernauer, E., *Fam. Cons. Sci. Res. J.*, 1985, **14**(1): 163-170.
- Yoo, S., Barker, R., *Textile Res. J.*, 2005, **75**(7): 531-539.
- Meirowitz, R., *J. Industrial Textiles*, 1998, **27**(3): 219-236.
- Gibson, P., *J. Coated Fabrics*, 1999, **28**: 300-327.
- Gibson, P., *J. Polymer Testing*, 2000, **19**(6): 673-691.
- Gibson, P., Rivin, D., Berezin, A., Nadezhdinskii, A., *Polymer-Plastics Tech. Eng.*, 1999, **38**(2): 221-239.
- Gibson, P., Rivin, D., Kendrick, C., *Int. J. Clothing Science Tech.*, 2000, **12**(2): 96-113.
- Gibson, P., Water Repellent Treatments on Battle Dress Uniform Fabric, U.S. Army Natick Research, Development, and Engineering Center Technical Report, 2005, Natick/TR-05/023.
- Stolwijk J, Hardy J, in *Handbook of Physiology*, 1977, H.K. Douglas, Ed., Am. Phys. Soc.: 45-69.
- Gibson, P., Multiphase Heat and Mass Transfer Through Hygroscopic Porous Media With Applications to Clothing Materials, U.S. Army Natick Research, Development, and Engineering Center Technical Report, 1996, Natick/TR-97/005.
- Gibson, P., Charmchi, M., *J. Soc. Fiber Science Tech. Japan, (Sen-i Gakkaishi)*, 1997, **53**: 183-194.