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Water Impermeable-Water Vapor Permeable Coated Fabrics

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THE limitations of rubberized coated fabrics, plastic films or plastic coated fabrics for use in rainwear apparel have long been recognized. While such materials afford effective protection from the rain, their very limited ability to transmit body perspiration away from the wearer results in the problem of heat build-up on the inside of the impermeable garment with resultant sweating and chilling. The following discussion deals with the research work, and laboratory and field testing involved in the development of the coated fabric to meet this need.

Background

Exploratory studies by C. L. Woodworth *(1)* at the Quartermaster Climatic Research Laboratory, Lawrence, Mass., were carried on to determine the limits of water vapor permeability necessary in a fabric for comfort. His work showed that in order for a water impermeable-water vapor permeable fabric to be practical its ability to transmit moisture vapor would have to closely approach that of an uncoated fabric. As a result, the first attempts to produce a water impermeable-water vapor permeable fabric centered around the improvement of the water resistance of the various water repellent treated fabrics.

Extensive work showed this line of attack to be difficult. While excellent moisture vapor transmission rates could be obtained with this type of treatment, no successful method could be found to develop a hydrostatic head of 75 cm. of water at the same time. This hydrostatic head, held for five minutes on the Suter Hydrostatic Head Tester, is the minimum requirement for waterproofness.

Having exhausted the possibilities in the above line of attack, the next approach seemed to be to develop into the waterproof rubberized coatings the property of moisture vapor transmission. It was immediately recognized that in order to achieve this end, it would be necessary to incorporate into the coating channels which would transmit moisture vapor. To accomplish this, without destroying the waterproofness, presented a most difficult problem. Mechanical or electrostatic perforation of the coated fabric destroyed the waterproofness while only improving the fabric's ability to transmit moisture vapor slightly.

The first theory developed as a means of transmitting moisture vapor through a rubberized fabric was the incorporation into a rubber matrix of a porous pigment in such a manner so that the pigment particles would touch each other. This would allow moisture vapor transmis-

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Note: The opinions expressed herein are those of the authors and are not to be construed as the official view of the Quartermaster Corps or the Department of the Army.

TABLE I—COMPARISON OF WATER IMPERMEABLE-WATER VAPOR PERMEABLE FABRICS WITH RUBBERIZED AND WATER REPELLENT FABRICS

	Moisture Vapor Trans. % of That Transmitted by Base Fabric	Hydrostatic Head cm. Water ASTM Test[a]	Suter Test[b]
Water Repellent Fabric	100	——	10–50
Rubberized Fabric	0–10	300+	278+
Treated Porous Pigment—Latex Binder	25	200	——
Untreated Porous Pigment—Latex Binder	42	250	——
Untreated Porous Pigment—Solvent Cement Binder	58	250	——
Solid Pigment—Solvent Cement Binder	73	300+	278+

[a] Fifth drop through a 3.12 in.^{2} area. [b] First drop through a 15.9 in.^{2} area.

sion through the coating from particle to particle of the pigment. In further development of the theory, a number of porous pigments were studied. Consideration was given to such properties as low density, low thermal conductivity, fireproofness, and mildew resistance.

The porous pigment finally selected had all of the above properties but was highly hydrophilic. Since it was planned to use a rubber latex as a binder, it was known that this highly hydrophilic pigment would coagulate the latex. In addition, a hydrophilic pigment in an open coating would absorb relatively large quantities of water. Therefore, a silicone treatment was added to the pigment, making it hydrophobic, and this treated pigment was then incorporated in the rubber latex. Coated fabrics were produced on a Tenter Frame Spreader and showed some measure of moisture vapor transmission.

Attempts were made to measure the air permeability of these moisture vapor permeable fabrics *(2)*. The values obtained were below the lower limit of such conventional apparatus as the Gurley Densometer or the Frazier Permeameter. Because relatively high rates of moisture vapor transfer had been obtained on these fabrics, it was concluded that there was no relation between air permeability and moisture vapor permeability on this type of fabric.

The development of a water impermeable-water vapor permeable fabric having shown some promise, a research contract was let with the Chemical Products Development Division of the Goodyear Tire & Rubber Company.

After experiments with various latices and production procedures, coated fabrics were produced on large scale equipment using the silicone-treated porous pigment and a synthetic rubber latex. Since these coated fabrics had relatively low rates of moisture vapor transfer when compared to uncoated fabrics, it was deemed necessary to conduct comfort tests to determine whether further work was warranted. Garments were constructed and sent to the University of Indiana for test.

During these tests, conducted by S. D. Gerking and Sid Robinson, of the Department of Physiology, Indiana University Medical School *(3)*, to determine the heat stress imposed by impermeable wet weather suits and the experimental water impermeable-water vapor permeable suits, the relative coolness of the following four types of clothing were compared:

1. Poplin jungle uniform.
2. Wet weather suit with permeable coating.
3. Wet weather suit laminated with permeable coating.
4. Impermeable wet weather suit.

All of the wet weather garments were made in the same design.

The experiments were performed on men walking on a treadmill at a metabolic rate of 190 Cal./M^2 per hour. The subjects used in the tests were all well acclimatized to the heat and maintained water balance during the two-hour experiments by drinking measured quantities of 0.1 percent salt solution. The wet weather suits were worn by the men in four different environments: air temperature 17.4°C. with 57% R.H., 24.1°C. with 50% R.H., 30.5°C. with 80% R.H., and 37.9°C. with 29% R.H. The latter environment was used to determine the maximum rate at which sweat could be evaporated from the clothing. In addition to the suits the subjects wore shorts, shoes, and socks in each experiment.

In all the two-hour experiments, the clothed and nude weights of the men were determined hourly in order to follow their rates of sweating and evaporation. The skin temperature of the men was measured at 15 minute intervals by four thermocouples placed separately on hip, chest, shoulder, and knee. Rectal temperatures were measured every half hour with a clinical thermometer, and heart rates were recorded at 15 minute intervals by an electrocardiotachometer. At air temperatures of 24.1°C., and 30.5°C., the comparisons of the clothing consisted of two experiments in which two men walked on the treadmill simultaneously.

In these studies, each subject wore each type of garment being considered. The data of both men for each type of garment were averaged to offset variations in the environment and the performance of the men from day to day. At 17.4°C. and 37.9°C., four subjects wore four different types of clothing in only one experiment each; thus, no direct comparison of the garments was obtained in these environments.

The water impermeable-water vapor permeable suits had a distinct advantage in a hot dry environment (37.9°C., 29% R.H.) where a high rate of evaporation was required. The subject who wore the impermeable suit under these conditions was barely able to complete one hour of work, while the subject who wore the water impermeable-water vapor prmeable suit was not taxed to complete two hours of the same work. Based on the rates of sweating, skin temperatures, rectal temperatures, percent of sweat evaporated, and heart rates of the men in all environments, the clothing was classified as to relative coolness in the following order:

1. Poplin jungle uniform.
2. Wet weather suit with permeable coating outside.
3. Wet weather suit laminated with permeable coating.
4. Impermeable wet weather suit.

These tests on water impermeable-moisture vapor permeable fabrics conclusively proved that the moisture vapor transmission rate was sufficiently great to be of practical value for specific application.

While the treated porous pigment-synthetic rubber latex combination did result in a coated fabric which was water impermeable and water vapor permeable, as shown by laboratory and comfort testing, the coating itself had many features which were objectionable from a processing and physical property standpoint. Because the basic spreading material was a water dispersion, difficulties were encountered with drying, shrinkage of fabrics, and corrosion of equipment. In addition to being costly and difficult to control, the coating was of an extremely weak nature. Extensive work resulted in limited progress in overcoming these difficulties. It became evident that new approaches would have to be investigated.

Concentrated effort soon brought about a number of entirely new concepts on the problem. A naturally occurring porous pigment was found which could be successfully used without the necessity of a water repellent treatment. Since the solubility of the silicone treatment had previously limited the binders to latices, this finding opened the possibility of the use of solvent rubber cements as binders. This meant that not only could the costly treatment be eliminated, but the coating material would lend itself to conventional rubber spreaders.

The porous pigment-rubber cement combination was successfully reduced to practice. Coated fabrics, which had excellent properties when compared with those of the treated pigment-rubber latex type, were produced on large scale equipment. While this coating was a marked improvement over the previous product, a number of necessary properties were still lacking. It lacked the required strength, possessed less than satisfactory aging characteristics as measured on the Weather-Ometer, and it failed to withstand washing and/or dry cleaning.

During the course of these investigations, experiments were undertaken using a solid pigment with a rubber cement, and it was discovered that a water impermeable-water vapor permeable fabric could be made with this combination. It was eventually demonstrated that this coating functioned by means of a complicated, three-dimensional interconnected structure of micropores Since this last approach had produced a coated fabric which had the most reproducible and satisfactory physical properties of the various coatings tried, its theory will be considered in more detail. It was work on this concept which finally produced the coated fabric presently developed to a usable stage.

While the early stages of this development have been discussed somewhat briefly, they do represent tremendous strides toward the development of a water impermeable-water vapor permeable fabric. This can be clearly seen from an examination of the data in Table 1.

Discussion

Theory

In order to obtain a porous coating using a solid pigment and rubber, an entirely different approach was used than has been normally recognized in this field. Using a solid pigment means that the pores have to be developed around the pigment in the coating upon drying. It is a known fact that because of their particle size and shape, pigments occupy much larger volumes than their true specific gravity indicates. This is true even under wetted centrifuged conditions and suggests that there is some void space between the pigment particles. If it is possible to add rubber to the pigment in such a volume as to bind the pigment particles together without occupying all of the void space available between the wetted packed particles, then it is possible to produce pores with the remaining void space upon drying the coating.

This theory might be more easily understood by considering an example: One hundred grams of a pigment having a specific gravity of 2.70 were found to occupy 127 cc. under wetted centrifuged conditions. Based upon its true specific gravity, 100 grams of this pigment should occupy only 37 cc. This would mean that 90 cc. of void space occurs between the pigment particles; this space would be available for binder and pores. If 50 cc. of binder were used to bind together the 100 gms. of pigment, then there would be 40 cc. of void space in the coating. On a percentage basis, this would mean that 31.5% of the coating would be voids.

A large number of pigments were examined under wetted centrifuged conditions. In some pigments, the available void space was considerably larger than in others. In fact, various grades of the same pigment were found to have extreme variation in the void space available. Knowing this, and considering the above theory, it could be seen that the pigment particle size and particle shape greatly influence both the number and the size of the pores developed.

It could then be visualized that a given volume of void space could be accomplished either by the production of a large number of small pores or by the production of a small number of large pores depending on the choice of the pigment. Producing and studying actual coatings was the only way to determine if this was true.

A large number of pigments and rubber binders were tried in varying ratios of pigment to binder. These blends were coated upon a base fabric and some of the resulting coatings were studied under a microscope. Figure 1 is the result of surface microscopic examination of these coated fabrics. It will be noted from the curve that in this type of coating, as theorized, the number of pores per square centimeter increases as the size of the pore decreases. Having established the existence of a wide variation of pore size and number within the sample coatings, it was most interesting to study the moisture vapor transfer and hydrostatic head resistance of these same coatings. Figure 2 indicates that moisture vapor transfer is obtained so long as a sufficient volume of pores is present, whether the pores be large or small. However, a trend could be noted toward a higher moisture vapor transfer in those coatings having a large number of small pores.

While the moisture vapor transfer was not influenced too greatly by the pore size, such was not the case with the hydrostatic head property. Examination of Figure 3 clearly indicates a steady increase in the hydrostatic head resistance as the pore size decreases. This graph also shows no appreciable increase in hydrostatic head until a pore size under 30 microns is attained. This ex-

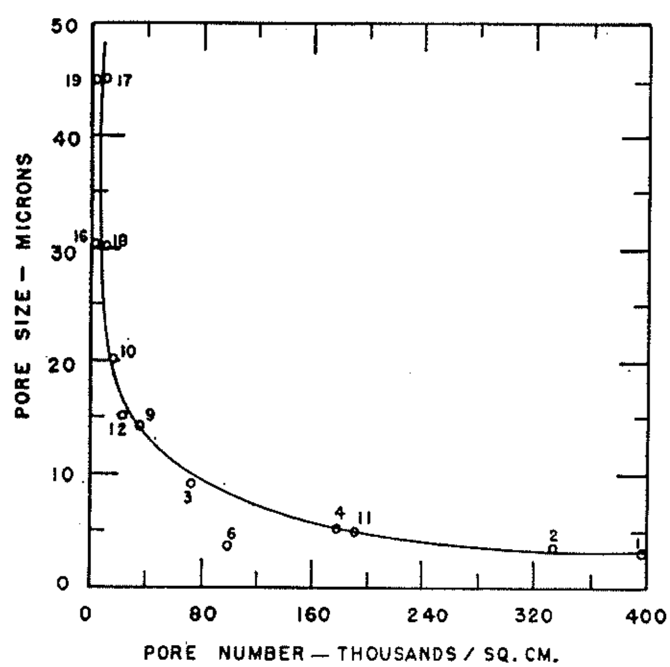

FIG. 1—Pore Number vs Pore Size.

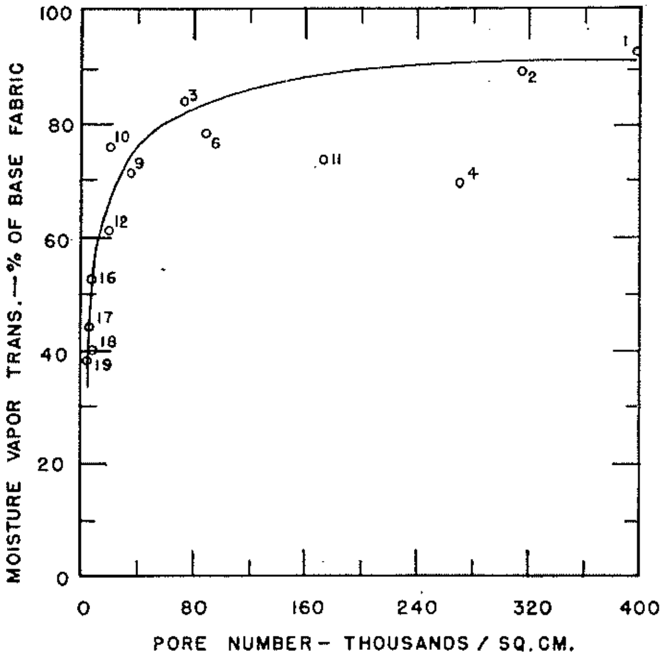

FIG. 2—Pore Number vs Moisture Vapor Transfer.

plains the probable reason for the loss in hydrostatic head resistance in the mechanically or electrostatically perforated coated fabrics.

Having established the requirements necessary to obtain a high rate of moisture vapor transfer as well as excellent hydrostatic head resistance, the task remained to select the pigment best suited for the job. It will be noted, in observing the graphs, that each point as plotted is represented by a number. These numbers correspond to the pigment used in producing the coating, so that the point labeled (10) on each of the graphs, represents properties obtained with a given pigment and resultant coating. Close observation of these graphs will indicate that some pigments produce more desirable properties than others. For instance, pigment (11) produced a good moisture vapor transfer, but a relatively low hydrostatic head resistance, while pigment (19) produced a low hydrostatic head resistance and a low rate of moisture vapor transfer. However, a number of pigments (1), (2), (3), (4), and (6) produced coatings which had hydrostatic head readings over 200 cm. of water and moisture vapor transfer values of over 60% of the transmission rate of the base fabric. It will be noted that all these coatings contained surface pores of under 10 microns in diameter, although the number of pores varied widely.

While the good results obtained on pigments (3), (4), and (6) might seem contradictory to the theory because of the small number of pores present, an explanation was found when the dissected coating was examined under the microscope. The accompanying photomicrograph (Figure 4) shows that the inner structure of the coating is not one of vertical pores, but rather is made up of a complicated structure of interconnected three-dimensional pores. Observation of the coatings indicated that this type of interconnected pore was much more prevalent in those coatings having the small-sized pores. Thus, through this interconnection within the coating, it was possible to transmit moisture vapor at a high rate even though there were wide variations in the number of surface pores.

Since a number of pigments were found which gave the desirable properties in this type of coating, the actual selection of the pigment was based on reproducibility on large scale equipment, cost, ease of handling in the process, and the resulting physical properties of the coating.

Physical Properties and Testing

It was realized that while the hydrostatic head and moisture vapor transmission properties of the coated fabric were important considerations, the coating itself would have to exhibit certain other basic properties if it were to be of practical use. Among these were flexibility, flex resistance, aging resistance, abrasion resistance, and washing and/or dry cleaning resistance. Consequently, work was begun to build a practical coating compound using the solid pigment-synthetic rubber combination.

In the "Theory" section, it was determined that the resultant coating would have to be composed of a large volume of pigment bound together with a binder. Because the pigment volume plus the void volume in the dried coating was so large in relation to the binder volume, it was necessary to select a binder which had high strength. In addition, it was deemed important to have a coating which was flexible and resistant to solvents. Although a large number of binders were investigated, the requirements were such that an oil-resistant synthetic rubber was finally selected.

The choice of the pigment, as directed by the theory, became rather clear cut. Of those pigments discussed in the "Theory" section, the one labeled (1) not only exhibited exceptional hydrostatic head and moisture vapor transmission properties, but also was low in cost, readily available, and lent itself to the process. This pigment was, therefore, chosen. Once the selection of the pigment and the rubber had been made, a great deal of time was spent in working out a compound which would have those physical properties desired.

To better understand the development of the final compound and its excellent physical properties, a backward glance must be taken to that stage of the development where an untreated porous pigment was being

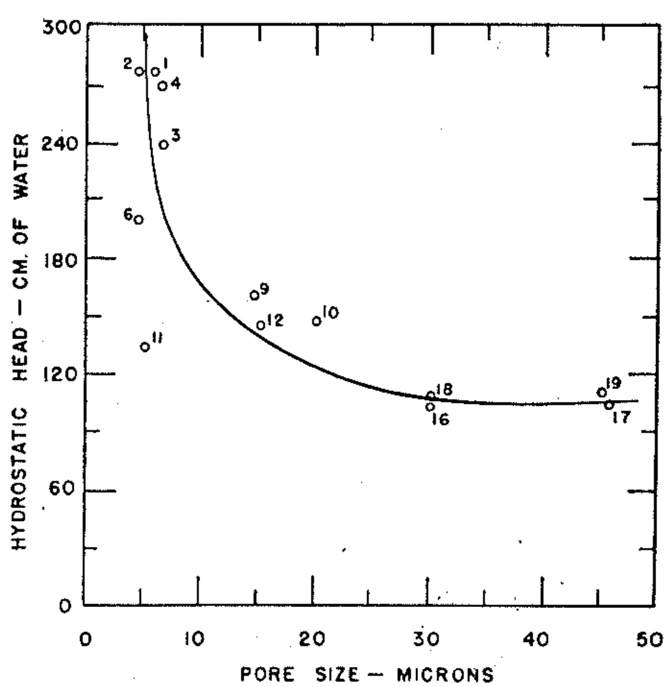

FIG. 3—Pore Size vs Hydrostatic Head.

used with a synthetic rubber binder. This combination, when used to produce a coated fabric, was then considered to exhibit such physical properties so as to warrant durability field testing. Its properties, as measured in the laboratory, are given in Table II.

Field tests were arranged at the Quartermaster Board Camp Lee, Virginia *(4)*. The technique employed involved four phases, namely: Rain, Obstacle, Glove, and Combat courses. Impermeable and uncoated garments were run for comparison purposes, along with the water impermeable-water vapor permeable garments. It was desired to determine water vapor permeability, durability of coating, and water impermeability of the latter garments. The objective of the tests was to determine if the experimental fabric had sufficient merit to warrant further development, and also the field test results were to serve as a guide in any resultant future work.

These tests were conducted and the results showed some deficiencies in the fabric. Examination of the tested experimental garments indicated that wherever leaking had occurred, it was due to low abrasion and flex resistance of the coating.

The comments of the test subjects, pertaining to each phase of the test, and the statistical analysis obtained, resulted in the recommendation and conclusion that work be continued on the experimental fabric with especial emphasis being placed on the toughening of the coating and improving the flexibility. In addition, it was suggested that in the future the portions of the test on moisture vapor transmission and degree of comfort be conducted under closely controlled conditions, as the perspiration rate varied so much between individuals that a true evaluation was not possible in a general field test.

The faults in the experimental fabric, as determined by field testing, had to be corrected. To accomplish this a number of more strenuous laboratory tests were needed along with basic changes in the compound.

The field tests showed that the hydrostatic head of the coated fabric, as obtained with the ASTM tester on the aged and unaged fabric, was insufficient to meet the needs. In order to obtain a more strenuous hydrostatic head test, the Suter machine was adopted as standard. An extension was added to this tester so that a maximum of 277 centimeters of water pressure could be applied. In this test, water pressure is applied over 5 times the sample area of the ASTM tester and failure is considered at the appearance of the first rather than the fifth drop.

To fully test the coated fabric for waterproofness, the modified Suter test was run on the fabric in its original condition, after 96 hours Weather-Ometer aging, after 1200 flexes on the Chrysler flex machine, and after

TABLE II—PHYSICAL PROPERTIES OF FIELD TESTED FABRIC
(Untreated Porous Pigment-Solvent Cement Binder)

Hydrostatic Head cm. H_2O ASTM (5th drop to penetrate)	249
Moisture Vapor Trans. % of Base Fabric (Open Cup method)	59
Hydrostatic Head cm. H_2O after 600 flexes (Chrysler Flex Machine)	180
Hydrostatic Head cm. H_2O after 96 hours Weather-ometer Aging	259
Taber Abrader Loss, grams after 1000 cycles using 500 gm. weight and CS-8 wheels	0.230
Weight of Coating, oz./yd.^{2}	3.1

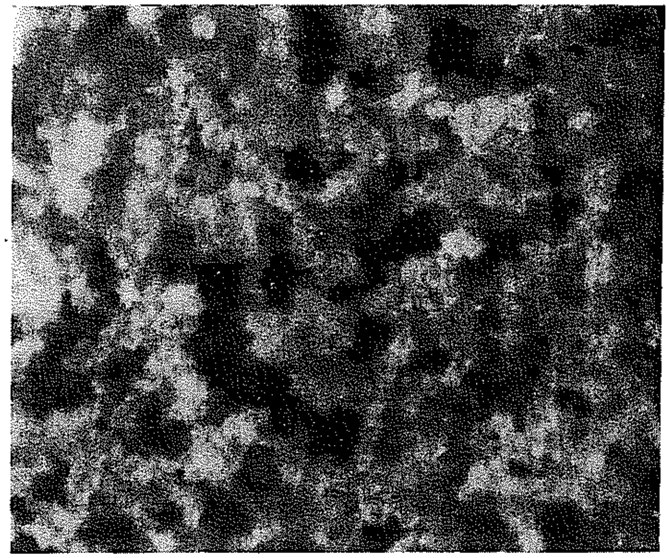

FIG. 4.—Horizontal cross section of water impermeable-water vapor permeable coating. (Magnification: 300X).

96 hours Weather-Ometer aging followed by 1200 flexes on the Chrysler flex machine. When the fabric which had been field tested was evaluated on these tests, the reason for leakage during the field tests was apparent. The Suter hydrostatic head resistance of the fabric after Weather-Ometer aging, followed by flexing, was extremely low.

The physical properties of the coated fabric as field tested represented the optimum properties obtainable with the porous pigment-rubber binder combination of that stage of the development. However, simultaneous work being carried on with the solid pigment-rubber combination was at such a point as to show its superiority over the porous pigment in obtaining high hydrostatic head resistance of the coated fabric. This combination also appeared to present more latitude in obtaining higher hydrostatic head resistance since the pore size could be varied by the choice of pigment whereas the pore size using the porous pigment was fixed.

Using the solid pigment-synthetic rubber combination discussed earlier in this section, it was found that the hydrostatic head resistance of the coated fabric after aging and flexing was superior to that obtained with the porous pigment-synthetic rubber combination. Since these hydrostatic head values were still under 100 centimeters of water, concerted efforts were made to improve this property.

The thought occurred that possibly the hydrostatic head resistance of the coated fabric might be raised if the angle of contact of the coating material was raised. In order to raise the angle of contact of the coating, it was necessary to incorporate into the coating, materials having a higher angle of contact than the coating itself.

Waxes, which are known to have a high angle of contact, and to bleed to the surface of a rubber compound, seemed a logical choice. In addition, two other benefits could be seen as a result of the bleeding action of the wax. First, the pore diameter would be reduced by the film of wax and, second, the aging of the compound would be improved. This second benefit might have been of prime importance since examination of the theory and basic structure of the coating brought to light that possibly unusual aging was taking place due to the open nature of the coating.

Table III—Typical Physical Properties of a Water Impermeable-Water Vapor Permeable Fabric
(Solid Pigment-Solvent Cement Binder)

Weight of Coating, oz./sq. yd.	4.0
Hydrostatic Head, cm. of water	
Original	277+
After flexing, 1200 flexes Chrysler flex	277+
After O_2 Bomb Aging, 96 hours	277+
After Weatherometer Aging, 96 hours	277+
After Weatherometer Aging, 96 hours + 1200 flexes	277+
After Resist. to Low Temp. (creased at —20° F.)	277+
After Washing (5 cycles)	112
After Dry-Cleaning (5 cycles)	109
Moisture Vapor Trans.—% of Base Fabric	
Original	73
After Washing (5 cycles)	75
After Dry-Cleaning (5 cycles)	75
Adhesion Pounds/2" width	
Original	6.7
Flexibility (Clark Softness) cm., @ 70° F. Warp	9.8
Filling	7.2
@ 0° F. Warp	11.1
Filling	8.6
After Heat Treat. 5 hours @ 220° F. Warp	10.1
Filling	7.7
Abrasion Resistance	
Taber abrasion, grams loss, CS 8 wheels, 500 gm. wt., 1000 rev.	0.100
Wyzenbeek (rubs to expose fabric) 6 lbs. tension, 3 lbs. pressure, 3/0 emery cloth	30
Blocking, 220° F., 30 min.	No blocking

Note: Fabric was 5.2 oz. water repellent Byrd cloth coated on one side.

Addition of the wax to the basic compound confirmed the above thinking in that the coated fabric, after being aged and flexed, exhibited a hydrostatic head resistance of well over 200 centimeters of water.

At the same time these improvements were being made in the compounding of the coating, investigations were undertaken to develop better coating techniques on various fabrics. Earlier work had shown that this type of coating could best be applied to tightly woven, fine thread, water repellent treated fabrics. A weight-of-coating study was made on such a fabric, and it was found that when 4.0 to 5.0 oz./sq. yd. of coating were applied, maximum physical properties were obtained. Coating weights as low as 2 oz./sq. yd. showed reasonably good properties, while coating weights of 8 oz./sq. yd., or above, tended to crack when bent sharply with the coating out.

It was found that the coating was best applied to the fabric in a three-coat operation: one tight coat, to anchor the coating to the fabric, and two spread coats in opposite directions to completely cover the fabric. Attempts to reduce the number of passes resulted in spotty hydrostatic head results because of incomplete coating around slubs and let-outs in the fabric.

Investigations have indicated that the coating can be successfully applied to one or both sides of the fabric and still retain high moisture vapor transmission rates. In addition to the tightly woven fabrics previously discussed, work has shown that excellent results can be obtained on such a fabric as sheeting. Here, to simulate fabric used in Army raincoats, a heavy coat was applied to one side of the fabric and a light coat to the other side. Actually, to meet the properties of the higher grade, 4.0 to 5.0 oz. one side coated fabrics, a heavier weight of coating was required (5.0 to 6.0 oz./sq. yd.).

During the entire development, it was recognized that the coated fabric would have to be cleaned by washing and/or dry cleaning. The coated fabric finally developed does withstand 5 cycles of either of these cleaning methods, retaining a Suter hydrostatic head of over 100 cm, of water.

As a result of the compounding studies and the improvement in coating techniques, it has been possible to produce on conventional rubber spreader equipment considerable yardage of a water impermeable-water vapor permeable coated fabric. A typical example of the data obtainable on this type of coated fabric is shown in Table III.

Examination of these data, along with those given in Table II, will show that not only have improvements been made in the waterproofness, both before and after aging, but also the moisture vapor transfer rate has been increased considerably. Another property of prime importance is the abrasion resistance. This has been increased more than twofold. It was coated fabric of this type which was field-tested for comfort at the Quartermaster Climatic Research Laboratory, Lawrence, Mass.

Arrangements were made to conduct comfort tests on the coated fabric at the Army Quartermaster Corps Climatic Research Laboratory, Lawrence, Mass. J. W. Eliot, R. Bader, W. Goddard, and H. Hanson, carried on this work *(5)*. The prime purpose of this work was to evaluate the moisture transmitting properties of the coated fabric.

Three types of fabric, of the same approximate weight, were used in this evaluation. Parka and trousers assemblies were fabricated using the water impermeable-water vapor permeable coated fabric and, for control, assemblies were made from an impermeable coated fabric and an uncoated fabric. Additional clothing worn by the subjects was selected on the basis as being the most likely to be worn in the field, with the same climatic conditions prevailing.

The tests were to simulate two separate field operations that might be encountered by individuals wearing parka and trousers. These were (1) as a continuous wear exposure suit, i.e., a garment capable of remaining immersion-proof should an aviator parachute into the sea, yet capable of transmitting perspiration from the aviator's clothing to maintain comfort during long periods of wear and, (2) a suit for use in wet-cold field conditions, where there is exposure to wetting from without and a high relative humidity making evaporation difficult from within.

To simulate those conditions prescribed, the climatic chambers during test were maintained at two conditions: (1) Temperate—Temperature at 75°F. and relative humidity at 50%, with wind velocity at 3.0 miles per hour; (2) Wet-Cold—Temperature at 30°F. and relative humidity at 60%, with wind velocity at 3.0 miles per hour.

Eight test subjects were selected and conditioned by walking on a treadmill (Figure 5) in the climatic chambers two hours a day, five days a week for two weeks.

After conditioning of the test subjects, the tests were conducted with a rotation of garments among the subjects so that various sweat rates could be averaged out. In the temperate experiments, the men were exposed for five hours, exercising by walking on level treadmills at 3.5 miles per hour for ten minutes and sitting quietly for the other twenty minutes of each half hour. In the wet-cold test plan, the test subjects were exposed for two hours, walking continuously on treadmills at 3.5 miles per hour.

Physiological measurements were made to determine the body weight change, moisture uptake of the garments, skin temperature, and rectal temperature. In addition, the test subjects' observations and calculations were recorded. The body weight change which was obtained by weighing the men nude before and after each exposure was used as an index of total sweat output. The moisture uptake was determined by obtaining the weight of each item of clothing before and after exposure. Skin temperatures were taken every ten minutes during the exposure by means of copper-constantan thermocouples attached to the skin. These thermocouples were read by a self-balancing recording potentiometer. The thermocouples were positioned as follows:

a. Underside of terminal phalanx of great toe.
b. Medial side of thigh, midway to knee.
c. Abdomen, two inches lateral to umbilicus.
d. Back, midline, at 7th cervical vertebra.
e. Back of calf.
f. Medial side of terminal phalanx of index finger.

The rectal temperatures were also taken at ten minute intervals and recorded in the same manner.

In their report on the tests, the authors state, "It is evident from body weight losses, moisture absorption of the uniforms and skin and rectal temperatures under these experimental conditions that the experimental semi-permeable material is far closer in its moisture transmitting behavior to the control permeable material than to the control impermeable material . . .

"Under both the wet-cold and temperate conditions the average total sweat loss was less with the semi-permeable fabric than with the impermeable fabric. Inasmuch as sweat production by the body is quantitatively indicative of the heat load being imposed by clothing, it is fair to state that this difference represented a decrease of better than 60 calories in the heat load imposed on each man during the periods of exposure.

"It is calculated that the total heat production of each man, both in the two-hour wet-cold exposures and in the five-hour temperate exposures, approximated 600 to 700 calories. This means that the heat load saved by use of the experimental fabrics under these conditions represented (very roughly) ten per cent of the total load imposed."

In addition the authors concluded, ". . . from a physiological point of view, standardization of Rain

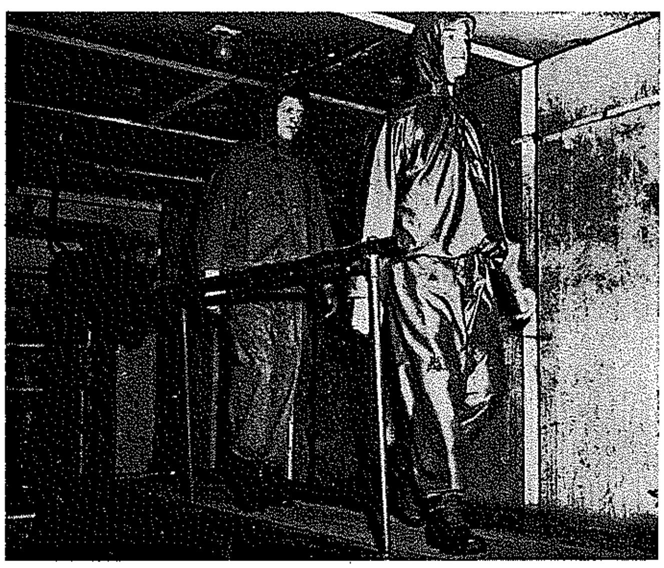

FIG. 5—Comfort Test: Man on the left wearing standard impermeable parka and trousers, man on the right wearing experimental vapor-permeable suit on treadmill at 3.5 m.p.h. under controlled environmental conditions.

TABLE IV—BODY PERSPIRATION TRANSMISSION AS DETERMINED BY CLIMATIC TESTING

Type Fabric In Garment	Impermeable Coated	Water Impermeable-Water Vapor Permeable Coated	Uncoated Fabric
% Perspiration transmitted through garment; transmitted average at 75° F.; 50% R. H.	56.2	84.5	85.4
% Perspiration transmitted through garment; transmitted average at 35° F.; 60% R. H.	43.4	64.9	65.6

Suits or even continuous-wear exposure suits manufactured from fabrics containing the degree of vapor permeability found in the experimental fabric tested here, is desirable."

Data in Table IV show exactly why the water impermeable-water vapor permeable coated fabric can be considered to be very close in its ability to transmit moisture vapor to that of the uncoated fabric.

Conclusions

A coated fabric has been developed which is waterproof and simulates uncoated fabric in wearing comfort. This coated fabric has good flexibility, flex resistance, aging resistance, abrasion resistance, and washing and/or dry cleaning resistance. Field testing and controlled climatic testing have indicated the usefulness of this coated fabric.

Further developmental work is in progress in the application of this coated fabric to such end items as tentage, sleeping bag covers, raincoats, footwear, and other items in which the properties of waterproofness and the ability to transmit water vapor are desirable.

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LITERATURE REFERENCES

(1) Woodworth, C. L., "One Way Permeable Fabrics," Quartermaster Climatic Research Laboratory, Lawrence, Mass.

(2) Bartell, F. E., Purcell, W. R., and Galluzzi, N. J., "The Determination of the Air Permeability of Highly Impermeable Fabrics," Preliminary Draft Interim Report No. 7 to National Research Council, Division of Medical Sciences (June 1, 1945).

(3) Gerking, S. D., and Robinson, S., "The Physiological Effects of Wet Weather Suits on Working Men," Indiana University Medical School (June 8, 1945).

(4) Derrick, L., "Test of Fabrics, Water Impermeable, Water Vapor Permeable," Report No. QMBT 646, Quartermaster Board, Camp Lee, Virginia (May 20, 1948).

(5) Eliot, J. W., Bader, R. M., Goddard, W. L., and Hanson, H. E., "Evaluation of Moisture Transmission by Experimental Vapor Permeable, Water Impermeable Fabric," Quartermaster Climatic Research Laboratory, Lawrence, Mass. (May 9, 1949).