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ELECTROSTATIC CHARGING ON FABRICS AT VARIOUS
HUMIDITIES

BY

P. J. SEREDA AND R. F. FELDMAN

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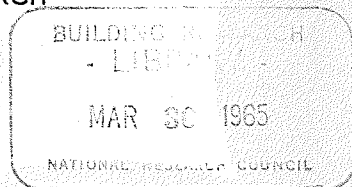
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La génération d'une charge électrostatique a été mesurée sur quatre tissus différents à des humidités relatives allant de 0 à 65%. On a également déterminé les isothermes de sorption. Pour tous les tissus on a constaté qu'un maximum se produisait dans les courbes de génération de charge lorsque l'humidité relative correspondait à W_m (la teneur en humidité lorsqu'une couche monomoléculaire d'eau est répartie sur toute la surface). Les résultats sont donnés par rapport aux isothermes de sorption.

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27—ELECTROSTATIC CHARGING ON FABRICS AT VARIOUS HUMIDITIES

By P. J. SEREDA and R. F. FELDMAN

Electrostatic-charge generation was measured on four different fabrics at relative humidities ranging from 0 to 65%. The sorption isotherms were also determined. For all fabrics, a maximum in the charge-generation curves was found to occur at a relative humidity corresponding to W_m (the moisture content when a monomolecular layer of water is completed on the surface). These results are explained with reference to the sorption isotherms.

It has been stated that, in our preoccupation with dramatic developments in the numerous fields of modern physics, we tend to forget our profound ignorance of some of the longest-known phenomena of physics⁵. Among these is static electrification. Much useful information on this subject was brought together in the symposium⁸ sponsored by the Institute of Physics in 1953.

Loeb⁵ questions much of the experimental work carried out in the past on this subject because sufficient attention was not given to the control of, and the accounting for, the sorbed water that is always present under normal conditions. Static electrification is a process involving the surface of a material, and, as such, it should be greatly influenced by sorbed water, which modifies the nature of the surface.

The Division of Building Research of the National Research Council of Canada has been concerned with the problem of the ignition of anaesthetic gases by electrostatic sparks generated on fabrics in use in operating rooms in hospitals. It has been suggested that the elimination of electrostatic charging on fabrics used for such applications can be accomplished by increased humidity. In this connection, information was sought regarding the relationship of electrostatic charging on fabrics to relative humidity. Such relationships for common fabrics were not found in the literature; hence the work that is reported here is justified.

Medley, working with wool fibres and strips of nylon, has reported that the frictional electrification is critically dependent on moisture concentration above a certain humidity⁶. He states that, below this humidity or with non-hygroscopic substances, electrification is limited by gaseous discharge between the rubbing surfaces. His results indicate an increasing tendency for electrification with increasing humidity in the low-humidity region, but this observation seems inconsistent with the explanation given above.

Keggin *et al.*, working with sliver as it is produced in a carding machine, have investigated the relation between moisture regain and the charge generated³. They have shown that the cellulosic fibres, cotton, flax, and viscose rayon, will develop considerably less static electrification than the protein fibres at moisture regains corresponding to 60 to 70% r.h. and from this they concluded that the amount and nature of the adsorption of moisture by fibres is possibly of more importance with regard to static electrification than is the chemical constitution.

These authors and others^{4,7} have shown that the resistivity of yarn and other textile materials increases exponentially with decrease in the relative humidity with which it is in equilibrium. Because of this relationship, it has been easy to explain the rapid decrease in the charge generation at high humidities on the basis of charge leakage or increased conductivity along the

surface-water films. It is difficult, however, to account for the observed maximum in the charge generation that was observed by Medley⁶ and by the present authors at an intermediate humidity. If simple gas discharge combined with charge leakage due to surface conductivity was the factor controlling the maximum charge, then it should occur at zero relative humidity. That the maximum occurred at an intermediate humidity suggested the possibility that a process involving the sorbed water and its interaction with the surface was responsible for the additive charging effect.

The present work was therefore planned to investigate how the sorbed water affected the charge generation of four different fabrics when they were separated from a nickel plate.

EXPERIMENTAL

Samples of fabrics used in these experiments were designated as :

- (1) Cotton drill — bleached, pure finish, 3/1 S-twill, approximately 6.3 oz/yd², 69 × 43 threads/in.
- (2) Nylon taffeta — white, plain weave, approximately 2.6 oz/yd², 170 × 90 threads/in.
- (3) Wool flannel — white, modified basket weave, worsted, approximately 7.1 oz/yd², 28 × 27 threads/in.
- (4) Propylon — greige, plain weave, approximately 3.6 oz/yd², 70 × 50 threads/in.

These samples were obtained in the condition as received from the manufacturers. They were cut to approximately 4 in. × 5 in. and washed in diethyl ether, ethyl alcohol, and distilled water in turn. After being washed, half of the samples of each fabric were dried over magnesium perchlorate and the other half were centrifuged (at 700 to 1,000 rev/min) to a spin-dry condition. Two series of vacuum desiccators, containing sulphuric acid solutions adjusted to concentrations to give relative humidity conditions of 20, 35, 50, and 65%, were used to condition the samples. Desiccators containing magnesium perchlorate were used to bring samples to the dry state.

One set of three samples of each fabric, representing the drying or desorption cycle (spin-dry), was placed in one series of desiccators, and one set of three samples of each fabric, representing the wetting or adsorption cycle (dry over magnesium perchlorate), was placed in the other series of desiccators. About one year elapsed during which samples could come to equilibrium. The charging experiments were carried out in a constant-humidity box equipped with gloves for the manipulation of apparatus without disturbing the conditions. The desiccator, with the samples inside it, was placed inside the box, and the relative-humidity condition in the box was brought to the same value as that in the desiccator. Only then were the samples removed from the desiccator for the charging experiments.

The charging apparatus consisted of a ½-in.-thick brass plate, nickel-plated, of 4 in. × 8 in., and a brass roller, 2½ in. in diameter and 5 in. long and also nickel-plated. By plating the brass plate and roller, a very smooth nickel surface was obtained. Nickel was selected because preliminary work indicated that it gave more reproducible results than other metals. An insulated handle on the roller allowed it to be rolled over the sample of cloth lying on the plate. A schematic diagram of the apparatus is shown in Fig. 1. By experiment, it was shown that the results were the same whether the plate and roller were earthed or not.

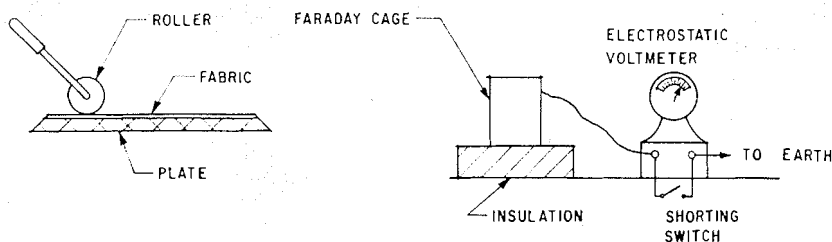


Fig. 1

Apparatus for measuring the charge on samples of fabric

After every ten passes of the roller, each pass requiring about $\frac{1}{2}$ sec to complete, the sample was lifted with insulated tongs and dropped into a Faraday cage. The test procedure was checked to show the effect of the rate of travel of the roller over the sample and also the effect of the rate of removal of the sample from the plate. Within the limits that can be realized when these operations are performed manually, these variables were not significant. The weight of the roller may be a factor, but this was not investigated. The potential was measured with an electrostatic voltmeter. The capacity of the measuring system and the sample was about 25 micromicrofarad and was assumed constant for all experiments. The experiment, consisting of ten passes, was repeated until a constant highest potential was attained or a maximum was followed by a decreased potential.

Before each series of experiments, any electrostatic charges on the sample were discharged by passing a radium C radio-active source over the sample and the apparatus. A representative sample of each textile material was taken for determination of the sorption isotherms. A sorption apparatus² was used to determine the isotherms.

RESULTS

The photomicrographs in Fig. 2 show the fibres and the weave of the different samples of fabric that were used. Figures 3 and 4 show the electrostatic potential on the fabric samples with each ten successive passes of the roller. Results of the charging tests were obtained on three separate samples of each fabric. The values of electrostatic potential that are reported in this paper represent average values for the three tests. Individual values, in most cases, varied less than 10% from the average, and, in all cases, it was found that the average value either approached a maximum or reached a maximum and then decreased. The curve for each material varied for different conditions of relative humidity. The samples represented different weaves, although there was no apparent correlation with weave. Cotton and nylon showed the same type of charging curve at 20% r.h., even when their respective weaves, as shown on the photomicrographs, differed in the extreme. On the other hand, nylon taffeta and propylon had similar weaves and their charging curves differed significantly at 65% r.h.

The highest values for the electrostatic potential were obtained by plotting the results of the charging tests as shown in Figures 3 and 4. These highest values were then plotted against the corresponding values of relative humidity to obtain the curves in Figures 5 to 8.

All the curves of highest electrostatic potential plotted against the relative-humidity conditions (Figures 5 to 8) showed maxima. It is surprising to find that the individual values of these maxima varied less than 10% from the average value for all the materials tested. Because this is within the limits of

experimental accuracy and reproducibility, it can be stated that all the fabrics attained the same maximum charge, although at different conditions of relative humidity.

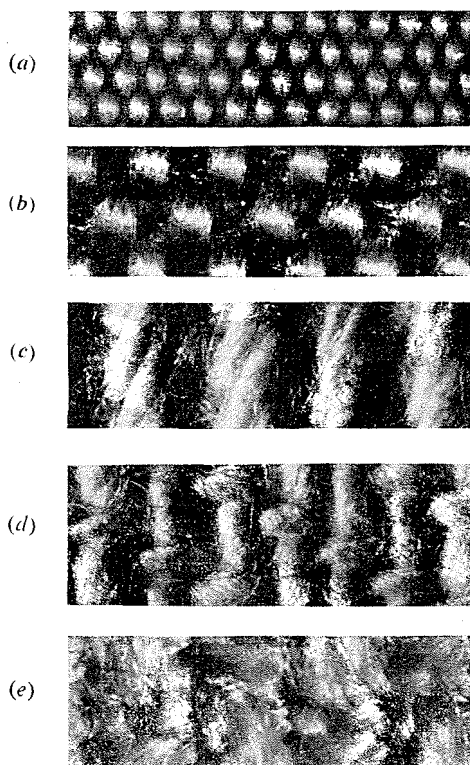


Fig. 2

Photomicrographs of fabrics ($\times 12.5$)

- (a) Nylon taffeta. (b) Propylon. (c) Cotton (front)
(d) Cotton (back). (e) Wool flannel

The charging curves for samples on the adsorption cycle often did not coincide with those for samples on the desorption cycle. This is consistent with the idea that the sorption of water on these materials would have a modifying influence on the charging property. The isotherms for these materials are given in Figures 9 and 10 and illustrate that, where the adsorption and desorption isotherms are separate, the two charging curves are usually also separate.

The determination of sorption isotherms and their classification and use in the calculation of the surface area of a variety of materials have been described by Brunauer¹. By calculations involving the B.E.T.* method from the isotherms obtained for the various textile materials investigated, it was possible to determine the surface area exposed to water sorption (assuming a water molecule to occupy an area of 10.8\AA^2); for some textile materials, this may be only the external surface of the fibres, whereas for others, such as cotton or wool, the fibres have an internal micropore system,

*Brunauer, Emmett, and Teller (see *J. Amer. Chem. Soc.*, 1938, 60, 309).

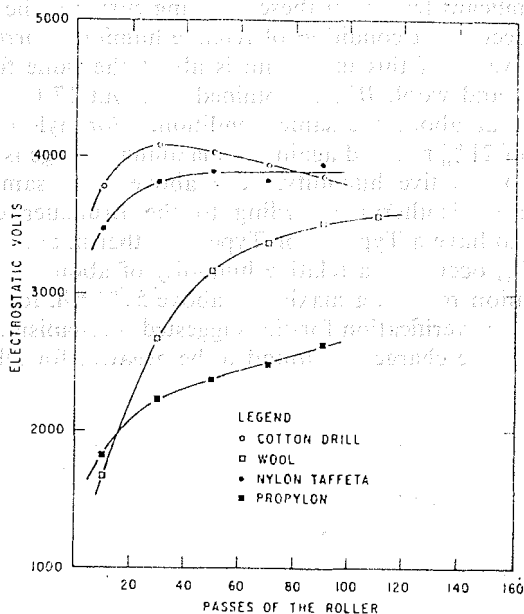


Fig. 3
Rate of charging at 20% r.h. (adsorption cycle)

where water can be sorbed. These calculations permit the determination of the relative-humidity condition and the corresponding water content, \bar{W}_m , when a monomolecular layer of water is completed during adsorption on the surface.

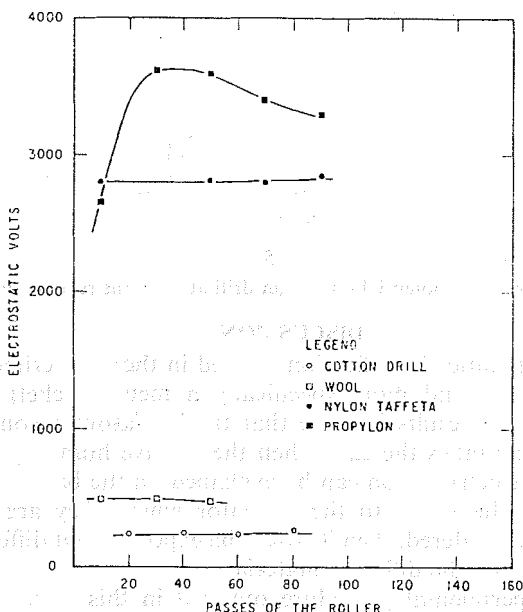


Fig. 4
Rate of charging at 65% r.h. (adsorption cycle)

The most significant feature of these charging curves is the fact that the maxima seem to occur at a condition of relative humidity corresponding to W_m and that the value of this maximum is about the same for all fabrics tested. For cotton and wool, W_m is obtained at about 17 to 18% r.h. and the maxima occur at about the same condition. For nylon taffeta, W_m occurs at a value of 21% r.h. and again the maximum charge is generated at about this value of relative humidity. The above three samples all give Type II or Type IV isotherm according to the Brunauer classification. Propylon appears to have a Type III or Type V isotherm, and it is generally considered that W_m occurs at a relative humidity of about 50% or higher. The charge generation reaches a maximum above 50% r.h. for this material and gives a significant verification for the suggested mechanism.

The polarity of the charge was found to be negative for all the samples tested.

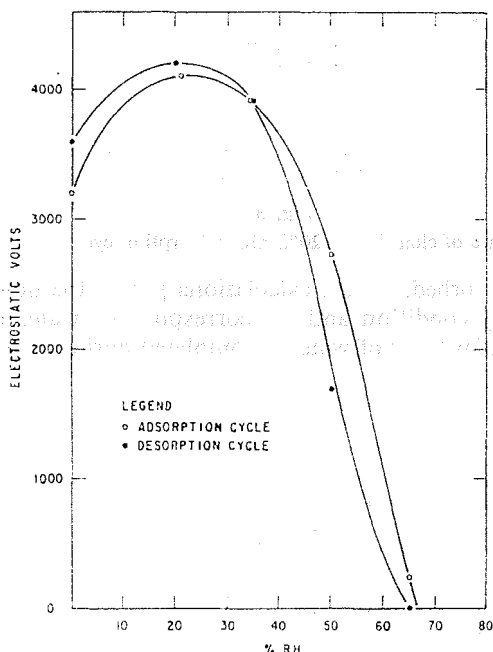


Fig. 5

Maximum electrostatic potential on cotton drill at different relative humidities

DISCUSSION

The system of static electrification studied in these experiments involves a solid-solid contact and more specifically a metal (nickel) to insulator (fabric) contact. The results indicate that the insulators become negatively charged, and, if one takes the case when the relative humidity is zero, then the mechanism of electrification can be explained on the basis of the transfer of electrons from the metal to the insulator where they are trapped. If transfer of ions is considered, then it would be expected that different polarity would be observed for the different materials.

When the experimental procedure outlined in this paper was used, a value of electrostatic potential was obtained which represented the maximum for the conditions of the experiment. It was found that variations in the

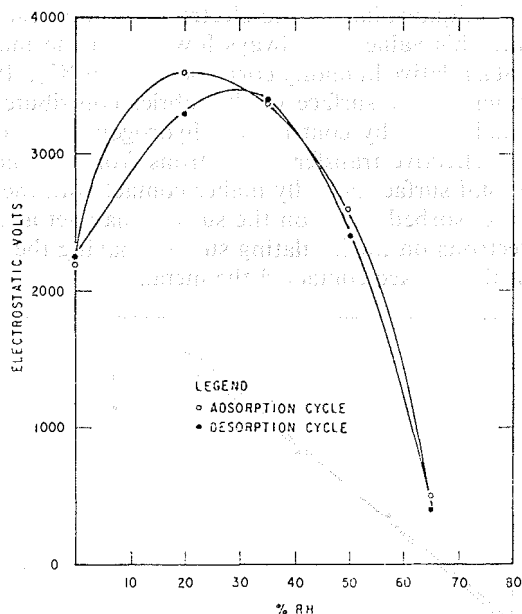


Fig. 6

Maximum electrostatic potential on wool at different relative humidities

procedure, such as rate of rolling or rate of removal of the sample from the plate, were not significant, although the size and weight of the roller might be a factor. Comparatively, the results do give an indication of the phenomena of electrostatic charging on different fabrics and show the influence of sorbed water.

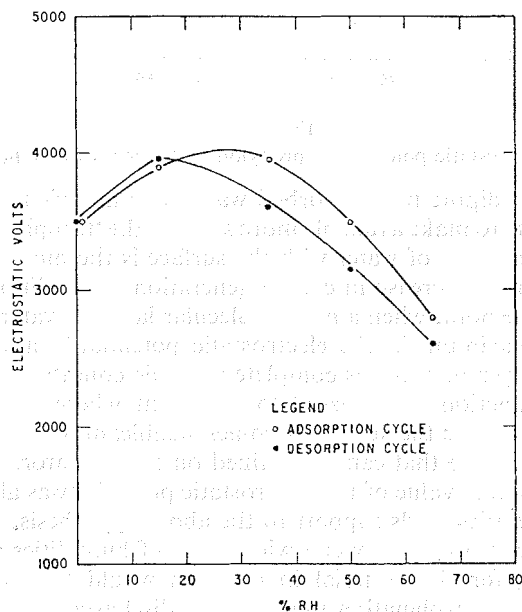


Fig. 7

Maximum electrostatic potential on nylon taffeta at different relative humidities

At zero r.h., a unique value for the electrostatic potential was obtained for each fabric, and this value was always lower than the maximum value that was observed at a relative humidity corresponding to W_m . It is postulated that the sorbed water on the surface of the fabrics contributed to a higher electrostatic potential either by contributing hydrogen ions to the metal or by allowing a more effective transfer of electrons from the metal. Because only a part of the total surface actually makes contact with the metal during the rolling procedure, sorbed water on the surface may act as a medium for distributing the electrons on the insulating surface, having the same effect as if a greater area of the surface contacted the metal.

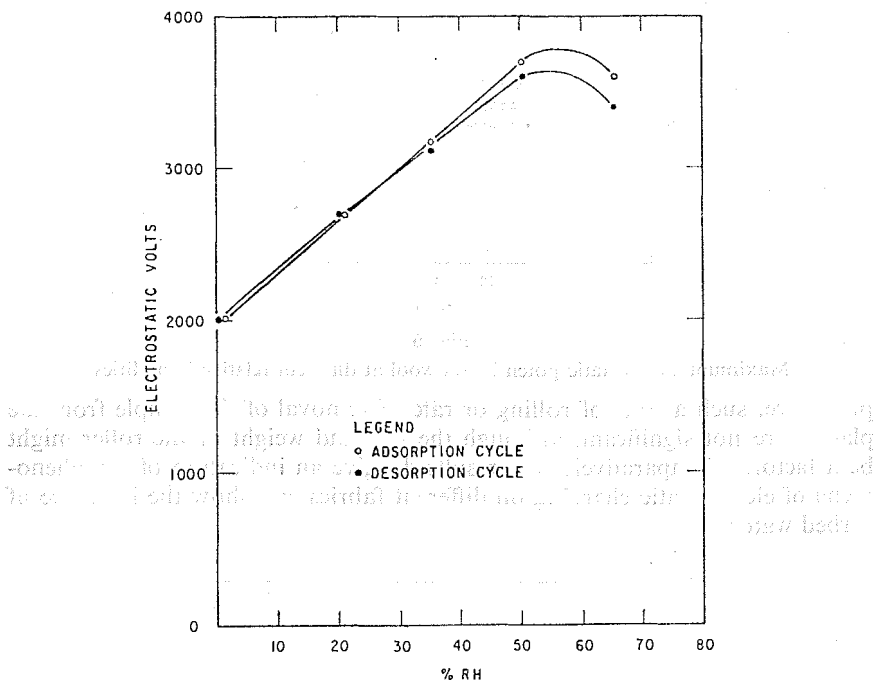


Fig. 8

Maximum electrostatic potential on propylon at different relative humidities

Because of its dipole nature, sorbed water may modify the character of the surface in a way to make available more sites for the 'trapping' of electrons. This effect of interaction of water with the surface is the more likely explanation of the observed increase in charge generation at conditions of relative humidity below the point when a monomolecular layer of water is present on the surface. A maximum in the electrostatic potential is attained when a monomolecular layer of water is complete; at this condition, it is expected that surface conduction is increased to the point where the effect of the 'leakage' of charge from the surface becomes significant and limits the value of the maximum charge that can be retained on the insulator. The fact that the observed maximum value of the electrostatic potential was about the same for the different fabrics lends support to the above hypothesis. The fact that the maximum does not extend over a wide range of humidities and occurs at the value of W_m for the material in question would tend to present an argument against the explanation that gaseous discharge controls the maximum charge, although it does not exclude the possibility that gaseous discharge or other mechanisms have some influence.

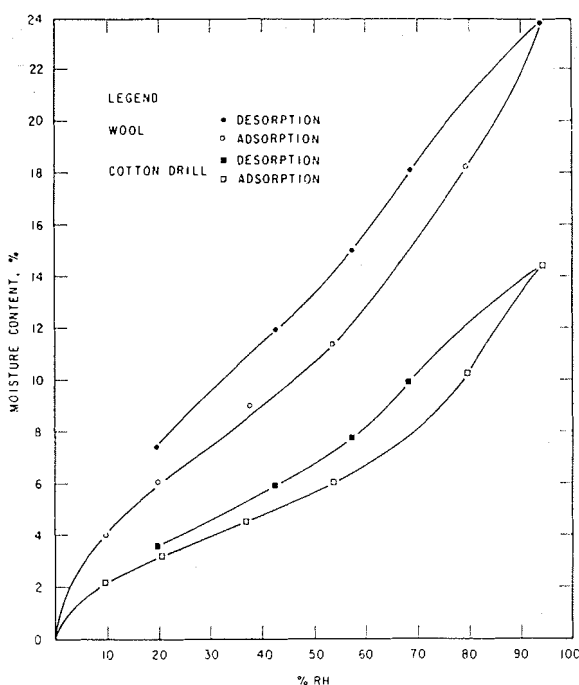


Fig. 9

Sorption isotherms for wool and cotton drill

Two processes are involved during any charging procedure: those of charge generation and charge dissipation. The charge that is observed at any instant in the procedure is the net charge. The influence of sorbed water on these two processes is expected to be dependent not only on the surface area but also on the nature of the surface. Thus, for propylon, which has a very low surface area, a small amount of sorbed water has a large effect upon the net charge, possibly because the charge dissipation or leakage is not affected and the increase in charge generation is reflected in the increase in the net charge. The charge-dissipation process could be defined in terms of the resistance of the fabric. In this respect, it would be useful to measure the resistance of the different fabrics at various levels of relative humidity, as was done for cotton by Murphy and Walker⁷. Such results would assist in explaining the portion of the charging curves at relative humidities above W_m , where the charge-dissipation process predominates. The slope of this portion of the curves is steeper for materials having a higher surface area because this corresponds to a higher quantity of water per unit weight of material, resulting in higher conductance or greater charge dissipation.

If the charge generation is so greatly modified by sorbed water, it follows that it will also be modified directly, because of shielding of the base material, by any substance that may be adsorbed on the surface, or indirectly by the effect this substance (impurity, or additive) may have on the sorption of water and its effect on surface conductivity. This effect was observed in some preliminary experiments in which the cotton was washed with a detergent. Samples of this cotton gave very low values for electrostatic potential at all conditions of relative humidity.

In this series of experiments, nylon staple and scoured wool did not give consistent results and are not included in this paper. These samples may have been contaminated with some surface impurity that was not removed completely by the washing treatment.

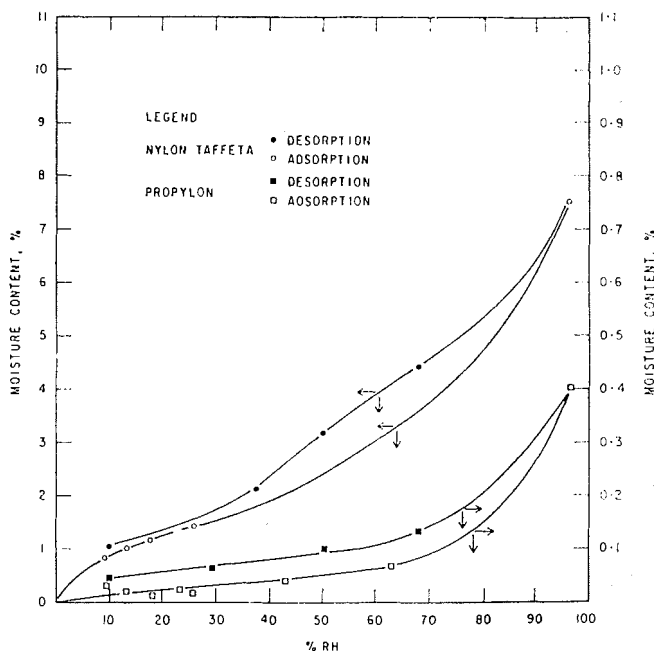


Fig. 10

Sorption isotherms for nylon taffeta and propylon

CONCLUSIONS

Tests have been made of the electrostatic-charge generation on samples of four different fabrics rolled with a nickel roller on a nickel plate. Electrostatic-charge generation appears to reach a maximum value at a relative humidity corresponding to that of a monomolecular layer of water existing on the surface of the material. Thus proof is presented in support of the postulated mechanism for the effect that sorbed water has on the electrostatic-charge generation.

It should be realized that these results apply only to samples of fabrics in an idealized state of cleanliness, where the surfaces are as free of any contamination as possible. This is justified when mechanisms are studied. The charging curves may be significantly different for these same fabrics under normal conditions of use, when dyes or residual washing agents as well as contaminants not readily removed may be present on the surfaces.

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