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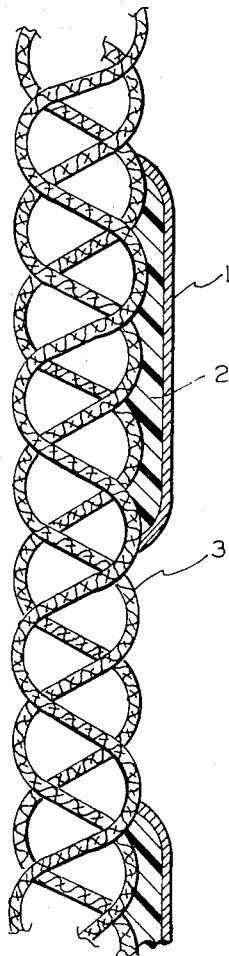
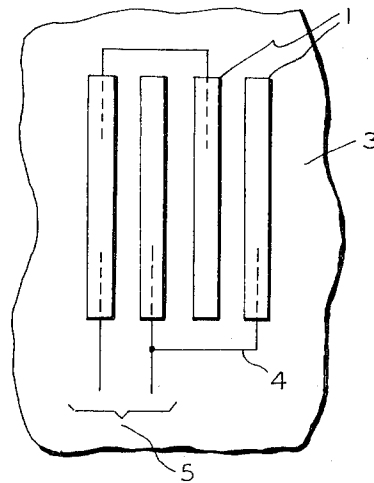
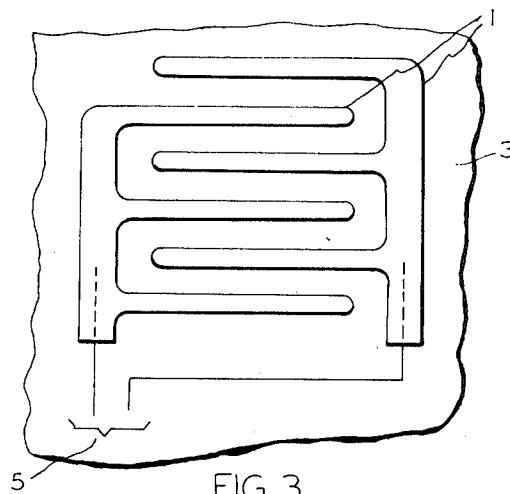
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3,550,439

CLOTHING HYGROMETER

Filed Sept. 30, 1968

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

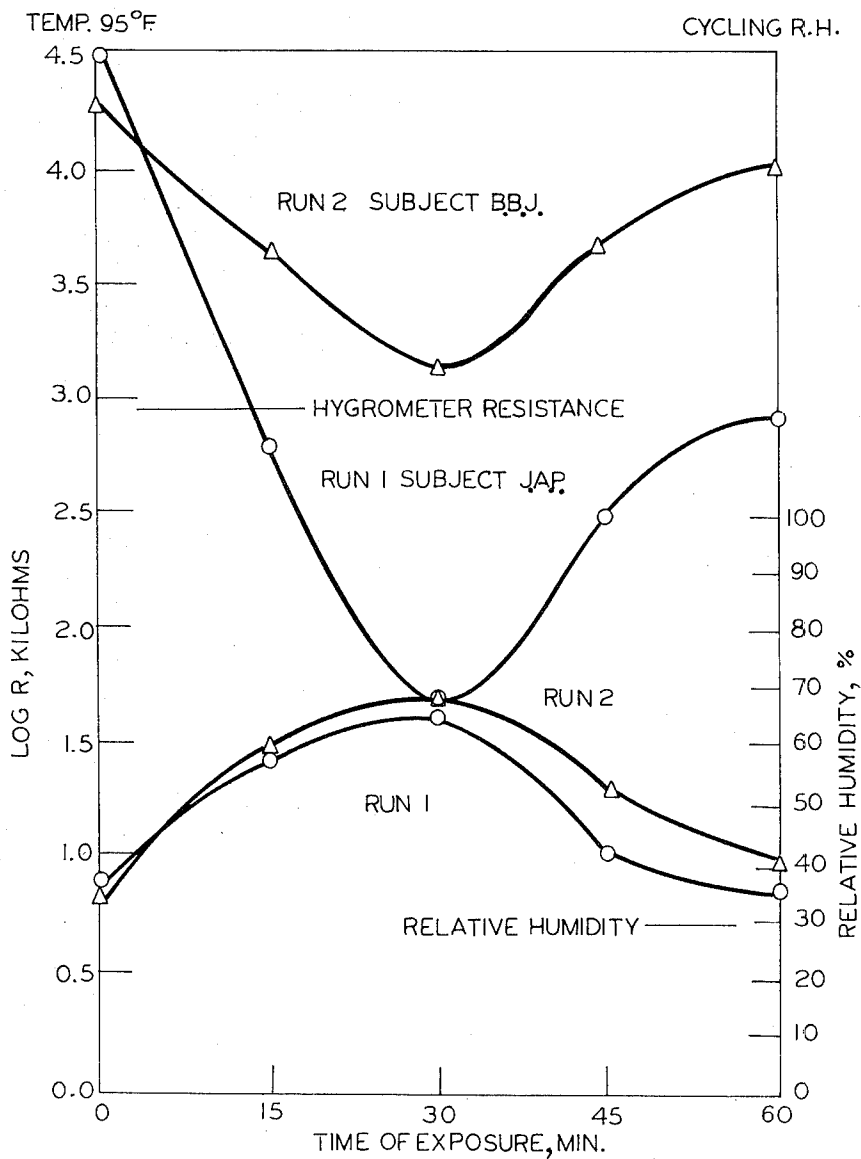


FIG. 4

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CLOTHING HYGROMETER

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2 Claims

ABSTRACT OF THE DISCLOSURE

An electrical device and a method of measuring moisture in textiles and other fibrous materials are disclosed. A manner of making the device is described. This device is a clothing hygrometer which comprises (1) a plastic film bonded to the textile, (2) an inorganic or organic hygroscopic metal salt, and (3) an overcoat of high conductivity such as evaporated metal films which remain solid to about 212° F. to form the hygrometer electrodes.

The device measures water content about from 0% to 50%, relative to the weight of the measured specimen, and is functional at temperatures about from 32° to 212° F.

A non-exclusive, irrevocable, royalty-free license in the invention herein described, throughout the world for all purposes of the United States Government, with the power to grant sublicenses for such purposes, is hereby granted to the Government of the United States of America.

This invention relates to a hygrometer and a method of measuring moisture content of textiles. More particularly, this invention relates to a clothing hygrometer which measures moisture content of textiles by means of electrical energy. This invention is primarily useful in measuring the moisture content of systems involving dynamic flow of moisture.

One object of the invention is to provide a device of relatively simple construction for measuring moisture content in garments made from fibrous materials.

A second object of the invention is to provide a method for determining moisture content of fibrous materials, such as cotton textiles.

A third object of the invention is to provide a method of fabrication of a clothing hygrometer.

A fourth object of the invention is to provide a means for measuring moisture content of surfaces where humidity tends to form through condensation, water being provided from any available source.

The invention includes the device for measuring moisture content, the method of making the device, and a method of using the device mainly as a clothing hygrometer. In general the hygrometer of this invention can be made by:

- (a) impregnating a fibrous specimen with an electrolyte solution containing an organic or inorganic hygroscopic metal salt,
- (b) allowing the electrolyte solvent to evaporate,
- (c) preparing a thin stencil or protective mask, dimensionally stable to heat, the stencil being the complementary pattern of the electrode arrangement (described in detail below) selected for the particular application,

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- (d) placing the stencil from (c) on the fibrous specimen,
- (e) applying a thin thermoplastic film on the masked surface of the fibrous specimen,
- (f) heating the assembly under pressures about from 1 to 50 pounds per square inch to the flow temperature of the plastic film, hence depositing the plastic film on the fibrous specimen,
- (g) separating the mask and unbonded plastic film from the specimen and subjecting the specimen to a second pressing to promote smooth transition of the plastic film edges into the fibrous surface,
- (h) depositing a thin metallic coating on the hot surface of the plastic coated areas of the fibrous specimen, and
- (i) attaching lead wires to the ends of the metallic coatings which serve as thin film electrodes.

Alternately, the plastic substance can be applied by other methods than that described in (c) above. Thus, it can also be applied by depositing a thin plastic film forming rigid substance on the fibrous specimen through the stencil and polymerizing the substance in situ.

The present hygrometer is especially adapted to measure the adsorbed or adsorbed moisture content of electrically nonconducting materials including textiles of cotton, wool, or blends with other fibers, and cellulosic papers. The thermoplastic component can be selected from the group of nontacky plastic materials such as polyethylene, polypropylene, polyamide, polyvinyl chloride, polyvinylidene chloride, and cellulose. Alternately, the plastic substance can be applied as a solution or emulsion of continuous film forming materials for textile and paper systems such as solutions or emulsions of polyacrylates, butadiene-acrylonitriles, butadiene-styrenes, polystyrenes, polyethylenes, polyisobutylenes, polyurethanes, polyvinylidenes, polyvinyl organosols, silicones, fluorocarbons, polyacrylamides, polyimines, styrene-maleic anhydride copolymers, epoxides, and melamines.

The hygrometer of this invention is used in conjunction with a standard electrical resistance meter. The observed resistance is then correlated with the moisture content of the fibrous material.

It is known that one can determine moisture content using hygroscopic salts and an electrode system across which the electrical resistance is measured; the resistance being proportional to the moisture content. ["Humidity and Moisture," Arnold Wexler (editor) volume 1, Section III "Electric Hygrometry," Reinhold Publishing Corporation, New York (1965).]

It is also known that moisture content of porous substrates predominantly determines their thermal insulating value, such as in clothing or in building construction insulation. [See Textile Res. J., 1965, Hollies.]

Before the present invention electric hygrometers had not been prepared in a thin, flexible form, such as would be required for measuring clothing properties on people. However, this invention permits measuring moisture differences from one surface to the other of a single fabric layer, a feature useful in monitoring dynamic transfer conditions, as well as measuring moisture collection in a skin-to-fabric interface. An advantage of the present device is that it is insensitive to moderate temperature changes.

Although the importance of water in determining the insulating values of clothing has been established, its importance in determining subjective comfort has been hampered by a lack of means to measure water in clothing

layers and between clothing layers, while being worn by people. This invention makes it possible to carry out these measurements.

This clothing hygrometer appears to have a number of unique characteristics which include: (1) sensing moisture present at the surface of a fabric over broad moisture level ranges, (2) it does not substantially alter the moisture transmission process of the system in which it is used, (3) it does not substantially alter the mechanical character of the fabric in which it is installed, and (4) it provides means for measuring moisture content in a small region of a large sample without isolating the sample.

In order that the invention may be better understood, reference is made to the following description and to the drawings in which:

FIG. 1 is an enlarged cross section of the device of this invention.

FIG. 2 is a plan view showing one pattern for spacing the electrode elements of this device and the wires which connect them to a resistance meter (not shown).

FIG. 3 is a plan view of an alternate arrangement of electrode elements.

FIG. 4 represents graphs of moisture measurements taken by means of the present device after the latter was sewn into the backs of the shirts worn by two volunteer subjects.

Referring to the figures, a thin thermoplastic film 2 is laminated by heat and pressure to the fabric substrate 3 through a non-adhering stencil (not shown) to give the electrode patterns selected (see FIGS. 2 and 3). Any arrangement of electrodes is acceptable provided they are (1) in the same plane, and (2) at a constant distance with respect to each other. Fine copper wires 4 (about A.W.G. 40) are used to connect common electrode sections, and to provide connections 5 to the resistance measuring device (not shown).

With specific reference to FIG. 1, fabric substrate 3 is initially soaked in a salt solution which, on drying, deposits the salt in and on the fibers. The fibers, so treated, then become the electrically conducting element sensitive to moisture content variation. The general appearance of textiles which have been treated in said manner, and which contain the electrically conducting film, has not been changed.

A thin metallic film 1 is evaporated in a known manner over the complete electrode area, resulting in a continuous conducting layer 2 on the thermoplastic film elements.

A number of electrode arrangements and the electrolyte concentrations are possible which would give an operable device. Nevertheless, electrode length, electrode separation, and electrolyte concentration should be chosen to give a reasonable resistance variation correlated to the moisture range within which practical application is desired. Generally, the electrode and electrolyte choices should give a device in a resistance range of about 1 to 1×10^6 ohms.

A preferred use of the invention would be that of using the device as a clothing hygrometer, one which would be useful in such investigations as determining comfort factors, and the like.

As an example, a 3¼ ounce 100% cotton printcloth swatch, approximately 6 inches square, was bonded to a polyethylene film, using the stencil technique described above, to give two electrode areas ½ inch wide, 3 inches long, and ½ inch apart. The swatch was saturated in .001 Molar kcl./aq. solution and air dried. Fine copper wires (about number 50 A.W.G.) were attached to the ends of each electrode and connected to a resistance bridge.

This particular hygrometer—prepared as above—was calibrated in a standard textile testing room (70° F. and 65% R.H.). Moisture was added dropwise and the electrical resistance measured when the water was fully distributed in the hygrometer. Table I shows the results obtained.

TABLE I.—CLOTHING HYGROMETER CALIBRATION

(.001 M kcl., 3-inch electrodes, ½-inch spacing)

Moisture added, percent: Resistance, ohms $\times 10^{-4}$		
0	-----	2000
10	-----	18.5
20	-----	9.7
30	-----	8.0
40	-----	7.0

USING THE DEVICE AS A CLOTHING HYGROMETER

A particular hygrometer of electrode design of FIG. 2 with 2-inch long electrodes, and prepared as described above was used in a subjective comfort experiment.

The hygrometer was sewn into a shirt in a manner which would place it next to the skin, on the back of the subject. The leads of the hygrometer were connected to a resistance meter. The shirt was worn by two different subjects in an environment of 95° F. and with varying (cycling) relative humidity. The high temperature together with increase in humidity caused the subjects to sweat, and this moisture was transferred to the sensing elements of the hygrometer. With each subject the sweating rate increased as the humidity was increased from 35% to 65%. The shirt and hygrometer worn by the subject with the lower sweating rate produced a resistance change from 20,000 ohms to 1,600 ohms. The subject with higher sweating rate produced a resistance change from 32,000 to 50 ohms. These results reflected the increased sweating with increased thermal stress of both subjects and the difference in sweating rate of the two subjects exposed to the same thermal stress.

The top two curves in FIG. 4 represent the resistance meter reading for the two different subjects. Subject JAP (Run 1) perspired more profusely than did subject BBJ (Run 2) hence the lower resistance readings in the case of the former at the high relative humidity (approx. 70% R.H. at the 30 minute time interval).

The bottom two curves in FIG. 4 are simply the time-relative humidity relationship taken by a recording humidistat.

We claim:

1. A method of preparing a clothing hygrometer which measures the flow of electric current between two electrodes secured to a fabric specimen substrate, said method comprising:

- impregnating a fabric specimen with a solution of a hygroscopic metal salt;
- allowing the solvent to evaporate;
- applying a thin stencil, dimensionally stable to heat, to the fabric surface, said stencil being the complementary pattern of the electrode arrangement;
- applying a thin, thermoplastic film to the stencil-covered surface of the fabric specimen;
- heating the assembly under pressure of about from 1 to 50 pounds per square inch to the flow temperature of the plastic film to bond portions of the plastic film to the fabric specimen in a pattern corresponding to that of the stencil;
- separating the stencil and unbonded portions of the plastic film from the fabric specimen, thereby leaving on the fabric surface a deposit of plastic film in the electrode pattern;
- submitting the specimen to a second heating and pressing step to promote smooth transition of the plastic film edges into the fabric surface;
- depositing a thin metallic coating on the hot surface of the plastic coated areas of the fabric specimen; and
- attaching lead wires to the ends of the metallic coatings.

2. A hygrometer for determining the moisture con-

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tent of fabrics by measuring the flow of electric current between spaced electrodes of predetermined pattern, said hygrometer comprising:

- (a) a fabric substrate to support hygrometer elements for attachment to the fabric whose moisture content is to be measured; 5
- (b) thin, thermoplastic, spaced coatings bonded to the surface of the fabric substrate, said thermoplastic coatings corresponding in pattern to a predetermined electrode pattern; 10
- (c) a thin metallic deposit on the surface of said thermoplastic coatings, said metallic deposit constituting the electrode; 15
- (d) a hygroscopic metal salt impregnated in said fabric substrate, said salt constituting a variably conductive electrolyte between said electrodes; and

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(e) means connected to the electrodes for conducting current to and from said electrodes.

References Cited

UNITED STATES PATENTS

3,058,079	10/1962	Jones	-----	338—35
3,071,746	1/1963	Kohl	-----	338—35

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