2
Textiles and moisture

2.1 Introduction

The properties of textile fibres are in many cases strongly affected by the atmospheric moisture content. Many fibres, particularly the natural ones, are hygroscopic in that they are able to absorb water vapour from a moist atmosphere and to give up water to a dry atmosphere. If sufficient time is allowed, equilibrium will be reached. The amount of moisture that such fibres contain strongly affects many of their most important physical properties. The consequence of this is that the moisture content of all textile products has to be taken into account when these properties are being measured. Furthermore because the percentage of moisture that can be retained by fibres is quite high (up to 40% with some fibres), the moisture content can have a significant effect on the mass of the material. This factor has a commercial importance in cases where material such as yarns and fibres is bought and sold by weight.

2.2 Effect of moisture on physical properties

The physical properties of fibres can be affected by their moisture content. In general the fibres that absorb the greatest amount of moisture are the ones whose properties change the most. Three main types of properties are affected.

2.2.1 Dimensional

The mass of the fibres is simply the sum of the mass of the dry fibre plus the mass of the water. The absorption of moisture by fibres causes them to swell, because of the insertion of water molecules between the previously tightly packed fibre molecules. Because the fibre molecules are long and narrow most of the available intermolecular spaces are along the length of the molecules rather than at the ends, so that the swelling takes place mainly in the fibre width as shown in Table 2.1. Nylon is a notable exception to this.

Table 2.1 The swelling of fibres due to moisture absorption [2]

Fibre	Transverse swelling		Longitudinal swelling (%)	Volume swelling (%)
	Diameter (%)	Area (%)		
Cotton	20, 23, 7	40, 42, 21		42, 44
Mercerised cotton	17	46, 24	0.1	
Viscose	25, 35, 52	50, 65, 67, 66, 113, 114	3.7, 4.8	109, 117, 115, 119, 123, 126, 74, 122, 127
Acetate	9, 11, 14, 0.6	6, 8	0.1, 0.3	
Wool	14.8–17	25, 26		36, 37, 41
Silk	16.5, 16.3–18.7	19	1.3, 1.6	30, 32
Nylon	1.9–2.6	1.6, 3.2	2.7–6.9	8.1–11.0

Table 2.1 is a summary of measurements made by different workers so that there is a certain amount of discrepancy among them. Because of the non-circular cross-section of a number of fibres, most notably cotton, the percentage change in cross-sectional area is a better measure than change in diameter. The change in volume of a fibre is linked to the changes in its length and cross-sectional area by simple geometry. The change in volume is also linked to the amount of water that has been absorbed. The swelling of fibres is a continuous process which takes place in step with their increasing moisture content. From this it follows that the swelling increases with the relative humidity of the atmosphere, the shape of the curve linking swelling to relative humidity being similar to that linking fibre regain with relative humidity [1].

Fabrics made from fibres that absorb large amounts of water are affected by the swelling. When such a fabric is soaked in water the increase in width of the fibres leads to an increase in diameter of the constituent yarns. Depending on the closeness of spacing of the yarns this can lead to a change in dimensions of the fabric. However, on subsequent drying out the structure does not necessarily revert to its original state. This behaviour is responsible for the dimensional stability problems of certain fabrics. Advantage is taken of fibre swelling in the construction of some types of waterproof fabrics whose structures are designed to close up when wetted, so making them more impermeable to water.

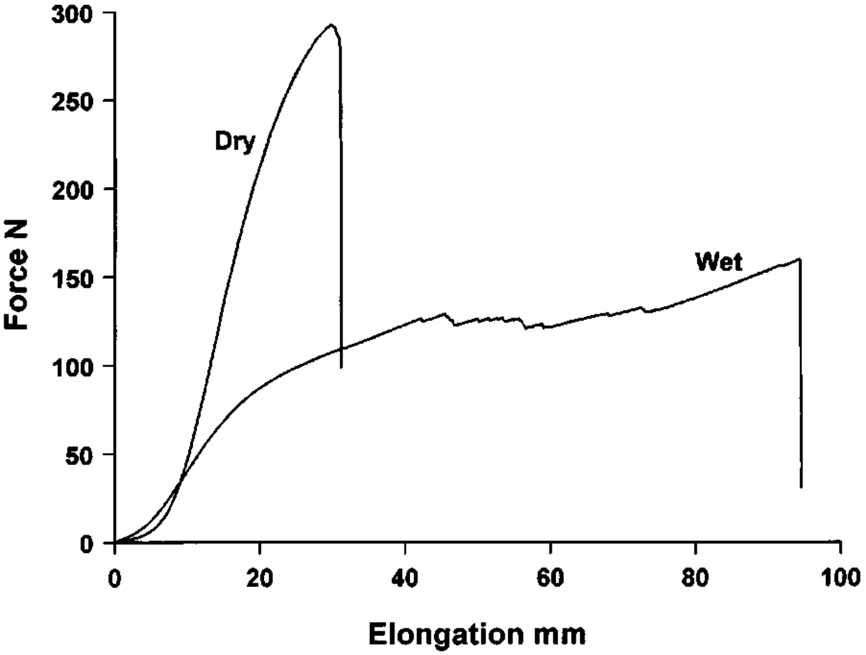
2.2.2 Mechanical

Some fibres, such as wool and viscose, lose strength when they absorb water and some, such as cotton, flax, hemp and jute, increase in strength.

Furthermore the extensibility, that is the extension at a given load, can increase for some fibres when they are wet. Figure 2.1 shows the loss in strength and the gain in elongation of a sample of wool tested when wet compared with a similar sample tested when dry. These changes in strength and extension have consequences for many other textile properties besides tensile strength. Some properties such as fabric tearing strength are ones that are obviously likely to be affected by fibre strength, but for other ones such as crease resistance or abrasion resistance the connection between them and changes in fibre tensile properties is less apparent. It is because of these changes in properties that textile tests should be carried out in a controlled atmosphere.

2.2.3 Electrical

The moisture content of fibres also has an important effect on their electrical properties. The main change is to their electrical resistance. The resistance decreases with increasing moisture content. For fibres that absorb water the following approximate relation between the electrical resistance and the moisture content holds for relative humidities between 30% and 90% [3, 4]:



2.1 The strength of wet and dry wool.

$$RM^n = k$$

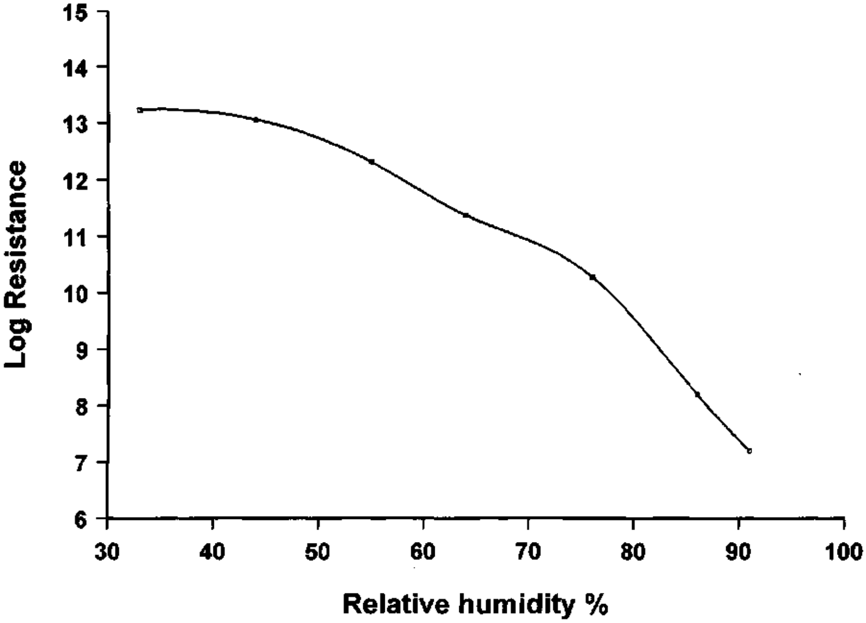
where R = resistance,
M = moisture content (%),
and n and k are constants.

The changes in resistance are large: there is approximately a tenfold decrease in resistance for every 13% increase in the relative humidity. Figure 2.2 shows the change in resistance with relative humidity for a sample of nylon [4]. This fall in resistance with increasing moisture content means that static electrical charges are more readily dissipated when the atmospheric relative humidity is high.

The relative permittivity (dielectric constant) of fibres increases with increasing moisture content in those fibres that absorb moisture [1]. Water itself has a much higher permittivity than the material making up the fibre and so as moisture is absorbed by the fibre the overall value is influenced by this, which will therefore affect any capacitance measurements, such as for evenness, which are made on textile materials.

2.3 Atmospheric moisture

The moisture content of textile materials when they are in equilibrium with their surroundings is determined by the amount of moisture in the air.

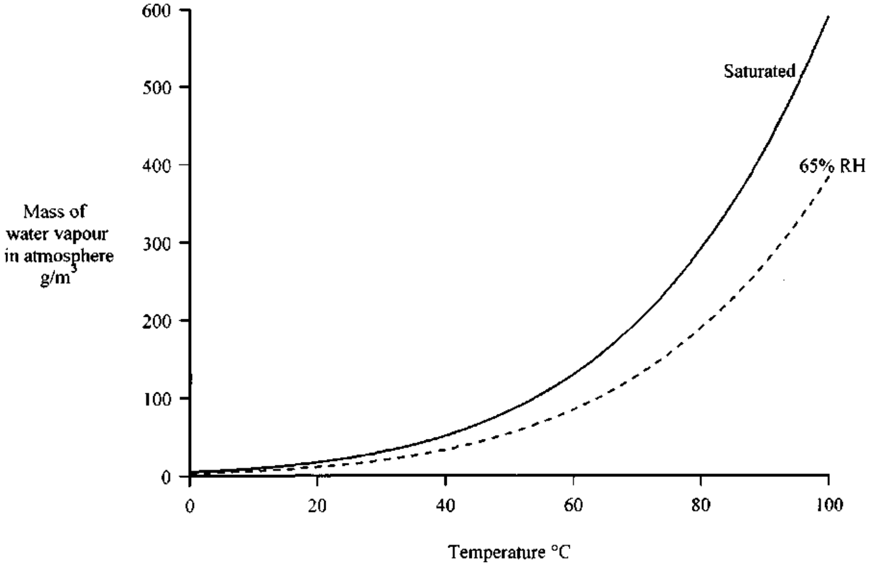


2.2 The change in resistance of nylon with relative humidity.

Therefore the moisture content of those materials that absorb water can vary from day to day or from room to room. The atmospheric moisture level is normally expressed in terms of relative humidity and not absolute water content.

2.3.1 Vapour pressure

Water molecules evaporate from the bulk at a rate determined by the exposed surface area and the temperature. Eventually the space above the surface reaches a stage when as many molecules are condensing back onto the surface as are evaporating from it. The space is then saturated with vapour. The amount of water held at saturation depends only on the temperature of the air and its value increases with increasing temperature as shown in Fig. 2.3. The pressure exerted by the water vapour is known as the saturated vapour pressure and is independent of the volume of space existing above the surface. If the vapour pressure in the space is kept higher than the saturated vapour pressure, water will condense back into the bulk. If, however, the vapour pressure is kept lower than the saturated vapour pressure, water will continue to evaporate from the surface until all the water has gone or the vapour pressures are equal. The total pressure above a surface is the pressure of the air plus the saturated vapour pres-



2.3 The mass of water vapour in the atmosphere (RH = relative humidity).

sure. For example at 20 °C the saturated vapour pressure of water is 17.5 mm Hg, if the atmospheric pressure is 760 mm Hg then the pressure of the air above a water surface is 742.5 mm Hg (Dalton's law of partial pressures).

2.3.2 Relative humidity

The amount of moisture that the atmosphere can hold increases with its temperature so that warmer air can hold more water than cold air. The converse of this is that when air containing moisture is cooled, a temperature is reached at which the air becomes saturated. At this point moisture will condense out from the atmosphere as a liquid: this temperature is known as the dew point.

When considering the effects of atmospheric moisture on textile materials the important quantity is not how much moisture the air already holds, but how much more it is capable of holding. This factor governs whether fibres will lose moisture to or gain moisture from the atmosphere. The capacity of the atmosphere to hold further moisture is calculated by taking the maximum possible atmospheric moisture content at a particular temperature and working out what percentage of it has already been taken up. This quantity is known as the relative humidity (RH) of the atmosphere and it can be defined in two ways. In terms of the mass of water vapour in the atmosphere:

$$\mathrm{RH} = \frac{\text{mass of water vapour in given volume of air}}{\begin{array}{c}\text{mass of water vapour required to saturate}\\ \text{this volume at the same temperature}\end{array}} \times 100\%$$

Alternatively it can also be defined as the ratio of the actual vapour pressure to the saturated vapour pressure at the same temperature expressed as a percentage:

$$\mathrm{RH} = \frac{\text{actual vapour pressure} \times 100\%}{\text{saturated vapour pressure}}$$

The absolute humidity is defined as the weight of water present in unit volume of moist air measured in grams per cubic metre.

It is important to note that the relative humidity of the atmosphere changes with temperature even when the total quantity of water vapour contained in the air remains the same. The dotted line in Fig. 2.3 shows the increase in the mass of water vapour contained in the atmosphere with increasing temperature for a constant relative humidity of 65%.

The amount of moisture contained by fibres that are in equilibrium with the atmosphere is dependent on the relative rather than the absolute humidity.

2.3.3 Standard atmosphere

Because of the important changes that occur in textile properties as the moisture content changes, it is necessary to specify the atmospheric conditions in which any testing is carried out. Therefore a standard atmosphere has been agreed for testing purposes [5] and is defined as a relative humidity of 65% and a temperature of 20 °C. For practical purposes certain tolerances in these values are allowed so that the testing atmosphere is RH 65% $\pm$ 2%, 20 $\pm$ 2 °C. In tropical regions a temperature of 27 $\pm$ 2 °C may be used.

2.3.4 Measurement of atmospheric moisture

There are a number of different instruments for measuring the moisture content of the atmosphere, known as hygrometers or psychrometers.

Wet and dry bulb hygrometer

If the bulb of a glass thermometer is surrounded by a wet sleeve of muslin in an atmosphere that is not saturated, water vapour will evaporate into the air at a rate proportional to the difference between the actual humidity and 100% humidity. Owing to the latent heat of evaporation, heat is drawn from the thermometer bulb, thus cooling it. This cooling effect has the consequence that the temperature indicated by a wet bulb thermometer is lower than the air temperature. By mounting two identical thermometers together, one with a wet sleeve and one with a normal bulb, the two temperatures can be read directly. The relative humidity can then be calculated from the temperature difference between the two readings. The value is usually read from appropriate tables. The rate of evaporation of water is also governed by the speed of the airflow past the wet bulb. Therefore for accurate work the rate of airflow past the thermometer bulbs has to be controlled as still air conditions are difficult to achieve in practice. The sling and the Assmann type hygrometers are two instruments in which the flow of air is controlled.

Sling or whirling hygrometer

This instrument works on the same principle as above but the two thermometers are mounted on a frame with a handle at one end. This allows them to be rotated by hand at a speed of two or three revolutions per second, so giving an air speed of at least 5 m/s past the thermometers. After half a minute of rotation, temperature readings from the two thermometers are taken and the procedure is then repeated until the readings have reached minimum values.

Assmann hygrometer

This is a more sophisticated instrument than the sling hygrometer in that a fan is used to draw air across the thermometer bulbs at a constant predetermined speed. The temperatures are read when they have reached a steady value.

Hair hygrometer

Human hair increases or decreases in length as the humidity of the surrounding air increases or decreases. By attaching a bundle of hairs to a suitable lever system, the relative humidity of the atmosphere can be indicated directly and, if required, recorded on a chart. The accuracy of this method is limited to within 3 or 4% of the true value for the range of relative humidities between 30% and 80%. A combined temperature and humidity recording instrument is often used in laboratories and is known as a thermo-hygrograph. The hair hygrometer requires frequent calibration and has a slow response to changes in atmospheric conditions.

2.4 Regain and moisture content

The amount of moisture in a fibre sample can be expressed as either regain or moisture content. Regain is the weight of water in a material expressed as a percentage of the oven dry weight:

$$\text{Regain} = \frac{100 \times W}{D}\%$$

where D is the dry weight and W is the weight of absorbed water.

Moisture content is the weight of water expressed as a percentage of the total weight

$$\text{Moisture content} = \frac{100 \times W}{D + W}\%$$

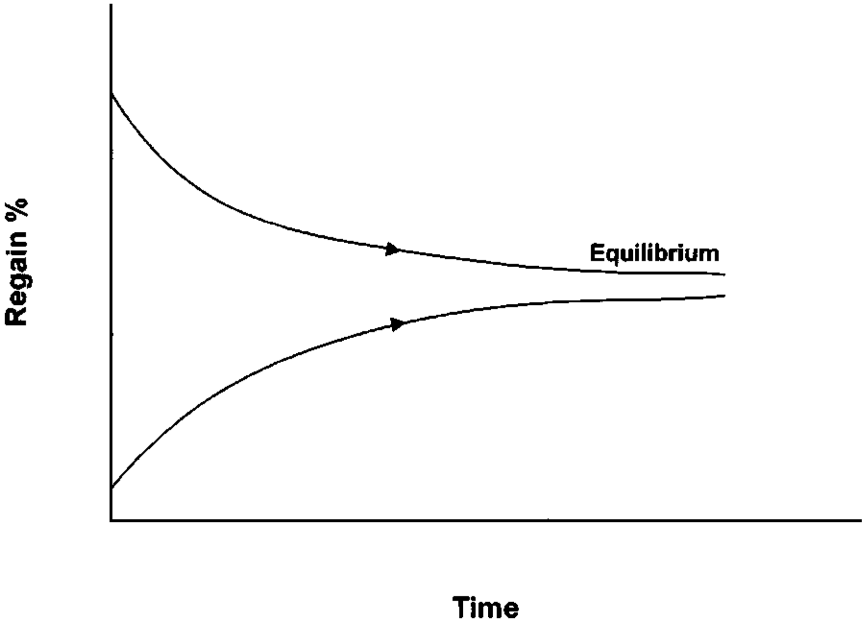
Regain is the quantity usually used in the textile industry.

2.4.1 Regain – humidity relations of textiles

Hysteresis

If two identical samples of fibre, one wet and one dry, are placed in a standard atmosphere of 65% RH, it might be expected that they would both eventually reach the same value of regain. However, this is not the case as the one that was originally wet is found to have a higher regain than the one that was originally dry; this is shown diagrammatically in Fig. 2.4. This difference is due to hysteresis between moisture uptake and moisture loss.

If the regain of a fibre that absorbs moisture is plotted against the atmospheric relative humidity as in Fig. 2.5 it is found to have an S – shaped curve and not a straight line relationship. If the relationship is plotted for decreasing relative humidity, that is when the fibres are drying out, it is found that the curve is different from that plotted for increasing relative humidity. It is this difference between the curves which is responsible for the difference in equilibrium regain values shown in Fig. 2.4. The dotted line in Fig. 2.5 at 65% relative humidity cuts the absorption and desorption curves at different values of regain. A sample that absorbed moisture in an atmosphere of 65% RH and reached equilibrium at the lower value of regain would then follow an intermediate path as it dried out. This phenomenon, which can result in two different values of regain at the same relative humidity depending on whether the sample is gaining or losing water, is important when samples are being conditioned. It is necessary for reproducibility of moisture content for a sample to approach equilibrium in the standard testing atmosphere from the same direction every time. Where this factor is important the samples are dried in an oven at a low temperature (50 °C) before conditioning in the standard atmosphere.

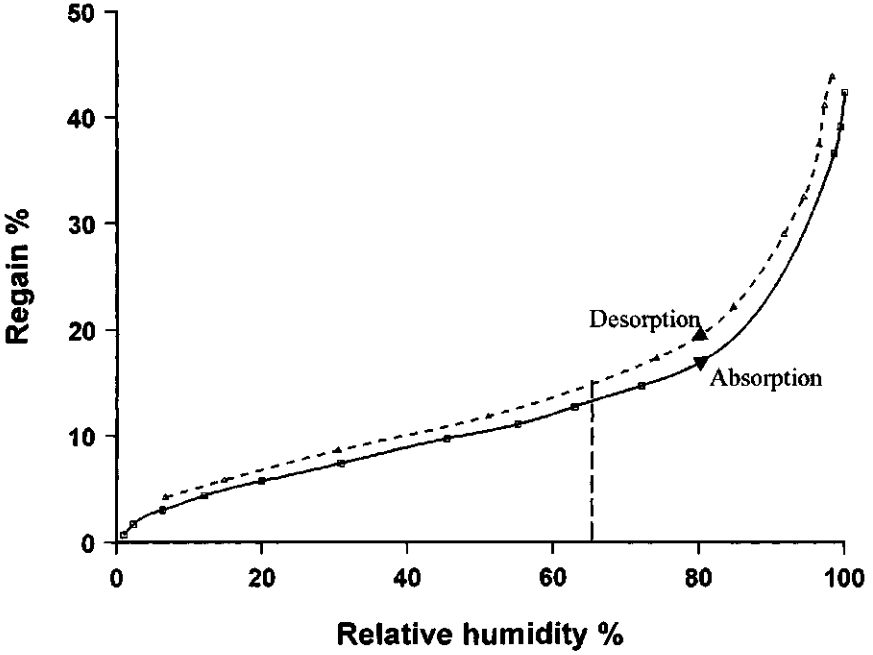


2.4 The hysteresis in moisture absorption.

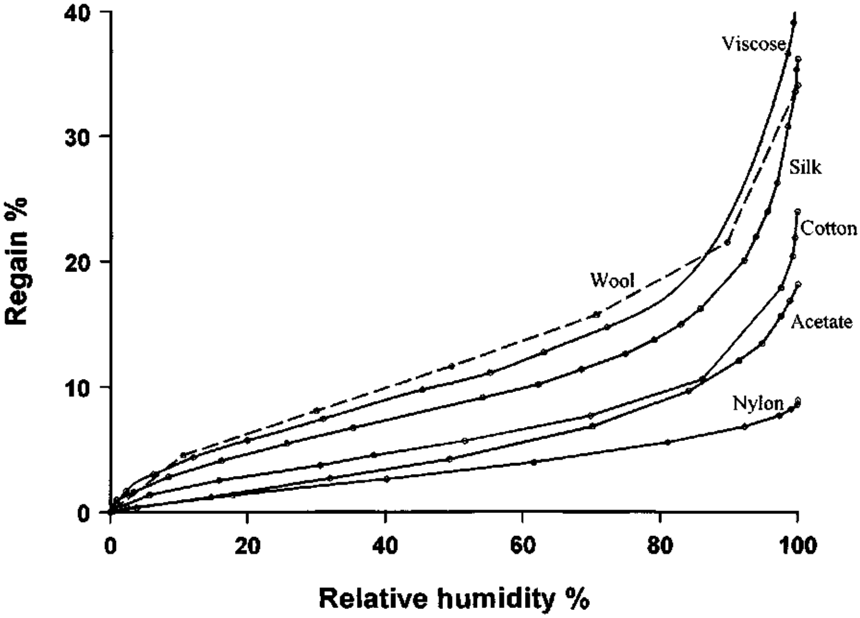
2.4.2 Factors affecting the regain

Different fibre types absorb different amounts of moisture depending on their affinity for water as shown in Fig. 2.6 [6–10]. For a given fibre type the moisture content is governed by a number of factors:

1 **Relative humidity**. The higher the relative humidity of the atmosphere, the higher is the regain of textile material which is exposed to it.
2 **Time**. Material that is in equilibrium at a particular relative humidity which is then moved to an atmosphere with a different relative humidity takes a certain amount of time to reach a new equilibrium. The time taken depends on the physical form of the material and how easily the moisture can reach or escape from the individual fibres. For example the British Standard for count testing [11] suggests a period of one hour for yarn in hank form to reach equilibrium, but three hours for yarn on packages.
3 **Temperature**. For practical purposes the temperature does not affect the regain of a sample.
4 **Previous history**. The moisture content of textile materials in equilibrium with a particular relative humidity depends on the previous history of the material. For example the hysteresis effect as mentioned above



2.5 A plot of regain versus relative humidity for viscose fibres.



2.6 A comparison of the moisture uptake of fibres.

means that it will have a different moisture content depending on whether it was previously wet or dry. Processing of the material can also change its regain value by altering its ability to absorb moisture. The removal of oils, waxes and other impurities can also change the regain by removing a barrier on the fibre surface to the flow of moisture vapour. For example the standard regain value for scoured wool is 16% and that for oil combed tops is 19%.

2.4.3 Methods of measuring regain

To measure the regain of a sample of textile material it is necessary to weigh the material, dry it and then weigh it again. The difference between the masses is then the mass of water in the sample.

$$\text{Regain} = \frac{\text{mass of water} \times 100\%}{\text{oven dry mass}}$$

Regain is based on the oven dry mass, which for most fibres is the constant mass obtained by drying at a temperature of 105 ± 2 °C. Constant mass is achieved by drying and weighing repeatedly until successive weighings differ by less than 0.05%. The relevant British Standard [12] specifies that successive weighings should be carried out at intervals of 15 min when using a ventilated oven, or at 5 min intervals if using a forced air oven. The exceptions to the above conditions are: acrylic fibres which should be dried in a normal oven at 110 ± 2 °C for 2 h and chlorofibres which should be dried at 77 ± 2 °C to constant mass.

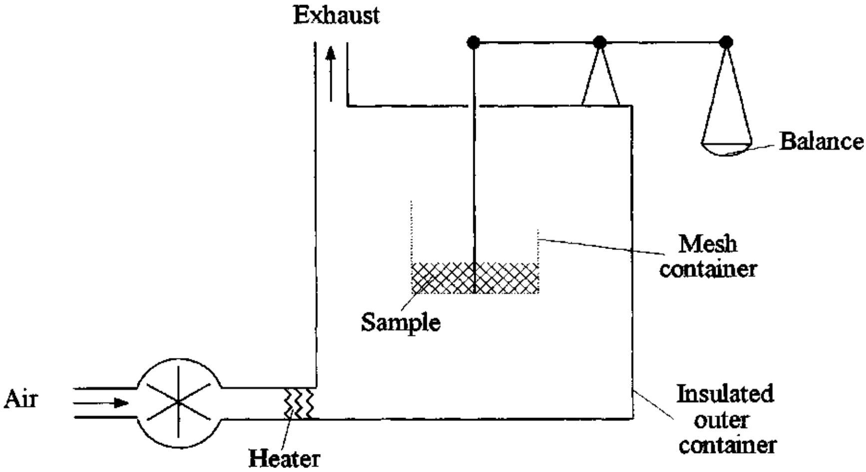
Conditioning oven

A conditioning oven, as shown in Fig. 2.7, is a large oven which contains the fibre sample in a mesh container. The container is suspended inside the oven from one pan of a balance, the mechanism of which is outside the oven. This ensures that the weight of the sample can be monitored without the need to remove it from the oven. A continual flow of air at the correct relative humidity is passed through the oven which is maintained at 105 °C.

The main advantage of using a conditioning oven for carrying out regain determinations is that all the weighing is carried out inside the oven. This means that the sample does not gain moisture as it is taken from the oven to the balance. The oven is also capable of drying large samples. The use of a conditioning oven to dry a sample is the correct standard procedure; any other method of sample drying has to be checked for accuracy against it.

The method is based on the assumption that the air drawn into the oven is at the standard atmospheric conditions. If this is not the case then a correction has to be made based on the actual temperature and relative humidity of the surrounding air.

The basis of the recommended correction [13] is to add the following percentage to the dry weight of the sample



2.7 A conditioning oven.

$$\text{Percentage correction} = 0.5(1 - 6.48 \times 10^4 \times E \times R)\%$$

where R = relative humidity %/100,
E = saturation vapour pressure in pascals at the temperature of the air entering the oven (taken from a table of values).

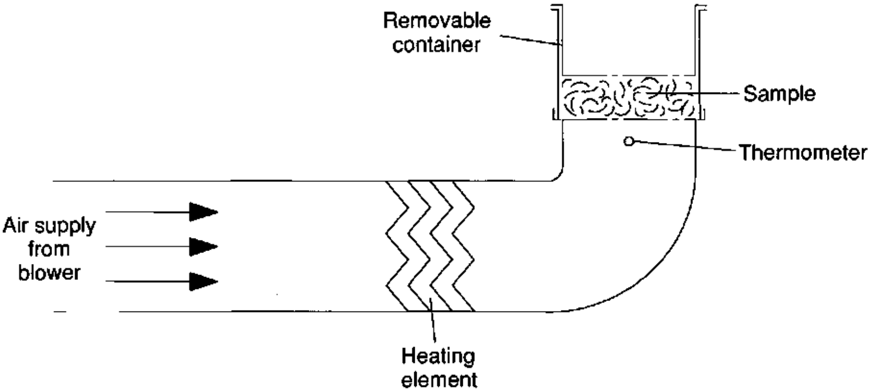
Rapid regain dryer

The rapid regain type of dryer represents a quicker way of drying fibre samples. The basis of this type of dryer is that the hot air is blown directly through the sample to speed up the drying process.

There are a number of different versions of this instrument, but in all cases the sample being dried has to be removed from the output end of the hot air blower and weighed on a separate balance. In some instruments a removable sample container which has interchangeable end caps is used. One end cap is a perforated one for use when the air is being blown through and the other end caps are a pair of solid ones which are placed on the container when it is removed from the heater for weighing.

The WIRA improved rapid regain dryer, shown in Fig. 2.8, uses a powerful blower to force air through the sample in order to give more rapid drying. Because of the high volume of heated air which can be passed through the instrument a large sample can be dried. This can either be weighed in its container or removed from the container and weighed separately.

The CSIRO (Commonwealth Scientific and Industrial Research Organization) direct reading regain dryer is similar in principle but has a vertical column with a removable sample container at the top. There is also



2.8 The WIRA process dryer.

a dedicated balance which forms part of the equipment and is calibrated to give the regain figure directly. Alternatively a balance may be connected to a computer which will calculate the regain from the weight. In order to achieve this the original sample is placed on the balance which is then zeroed before drying. As the sample then dries out, the balance indicates percentage regain.

When an external balance is used to weigh heated samples certain precautions have to be made:

1 The balance should be enclosed.
2 The time for weighing should not exceed 20s from removal of the sample from the dryer.
3 A buoyancy correction should be determined by using a dummy sample of steel wool which is weighed when cold and then reweighed after heating for a set time (5 or 15 min).

Electrical methods

The electrical properties of fibres change quite markedly with their moisture content so that the measurement of resistance or capacitance changes can be used to give an indirect method of regain determination.

The resistance change is a more suitable basis for an instrument as there is a greater change in the resistance of fibres with moisture content than there is in the capacitance. Furthermore the weight and distribution of material between the plates of a capacitor must be closely controlled in order to give reproducible results.

The great advantages that electrical methods possess over drying and weighing methods are the speed and ease of reading, the fact that they can be calibrated directly in regain units and the ease with which instruments can be made portable.

The disadvantages of electrical methods are the need to recalibrate them as they are indirect methods, the variations in readings due to packing density, the possible presence of dyes, antistatic agents and also variations in fibre quality.

In a typical electrical resistance measuring instrument, two electrodes are pushed into a package of yarn and the resistance between the electrodes is measured by suitable electronics, the answer being displayed on a scale which is directly calibrated in regain values. Different electrode sets are used for different packages, for example long thick prongs for bales and short needle like probes for yarn packages. The instrument usually has to be calibrated for the type of probe, the type of fibre and the expected regain range.

2.5 Correct invoice weight

When textile materials are bought and sold by weight, it is necessary for there to be agreement between buyer and seller on the exact weight that has to be paid for. This value can vary considerably with the moisture content of the material which in turn varies with type of material, the atmospheric moisture content at the time and how wet or dry the material was before it was packed, among other factors. The buyer certainly does not wish to pay for excess water at the same price per kilogram as the textile material. A 'correct invoice weight' is therefore determined according to [12]. In this procedure the consignment is considered to contain a percentage of water known as the standard regain allowance and the weight of the consignment is calculated as if it contained this amount of water.

When a consignment of textile material is delivered and weighed, a sample is taken from it on which tests are made which enable the correct invoice weight to be calculated. Samples of at least 200 g are selected according to adequate sampling procedures and immediately stored in airtight containers so that no moisture is lost. The samples are weighed and then the oven dry weight is determined as described above. In some cases other non-textile materials, such as oils, grease, wax and size, are removed before drying.

If M = mass of consignment at time of sampling, D = oven dry mass of sample, S = original mass of sample and C = oven dry mass of the consignment:

$$C = M \times \frac{D}{S}$$

To the oven dry mass is added an official allowance for moisture depending on the nature of the material. This regain allowance, sometimes called the 'official' or 'standard' regain, is set out in BS 4784. These values are only approximately the regains the materials would have when in equilibrium with the standard atmosphere and represent agreed commercial numbers for the purposes of determining quantities such as consignment weights, yarn counts and percentage compositions which vary with moisture content.

The regain allowances vary depending on what physical state the material is in, for example woollen yarn 17%, worsted yarn 18.25%, oil combed tops 19%, wool cloth 16%.

$$\text{Correct invoice weight} = C \times \left(\frac{100 + R_1}{100}\right)$$

where R_1 = commercial moisture regain.

Table 2.2 Regain allowances. Note that regain values depend on the form of the material

Fibre type	UK regain (%)	US regain (%)
Man-made fibres		
Acetate	(9)	6.5
Acrylic	2	1.5
Nylon 6, 6 and 6	(6.25)	4.5
Polyester	(1.5)	0.4
Polypropylene	(2)	0
Triacetate	(7)	3.5
Viscose	(13)	11
Natural fibres		
Cotton – natural yarn	8.5	7
Linen fibre	12	12
Linen yarn	12	8.75
Silk	11	11
Wool – worsted yarn	18.25	13.6
Wool – fibre clean scoured	17	13.6

Figures in brackets commercial allowances for cleaned fibres.
Source: taken from [12] and [13].

If the samples are dried after cleaning a different set of allowances is used for moisture and oil content, etc:

$$\text{Correct invoice weight} = C \times \left(\frac{100 + R_2 + A_2 + B_2}{100}\right)$$

where R_2 is the moisture regain which may differ from R_1, A_2 is the allowance for natural grease and B_2 is the allowance for added oil. In most cases an overall allowance is given which includes the values for moisture and natural and added fatty matter.

In the case of a blend the overall allowance is calculated from the fraction of each component in the blend multiplied by its regain value, for example: 50/50 wool / viscose (dry percentages)

$$\frac{50 \times 17}{100} + \frac{50 \times 13}{100} = 8.5 + 6.5 = 15\%$$

Regain values vary slightly from country to country. For instance, the USA has a single value of 13.6% for wool in all its forms but has separate values for natural cotton yarn (7.0%), dyed cotton yarn (8.0%) and mercerised cotton yarn (8.5%), although there is no value laid down for raw cotton. Therefore the appropriate standard should be consulted for the correct commercial regain figures. Table 2.2 is intended only as a guide.

Table 2.3 The relative humidity of air over saturated solutions of salts at 20 °C

Saturated salt solution	Relative humidity (%)
Potassium sulphate	97
Potassium nitrate	93
Potassium chloride	86
Ammonium sulphate	81
Sodium chloride	76
Sodium nitrite	66
Ammonium nitrate	65
Sodium dichromate	55
Magnesium nitrate	55
Potassium carbonate	44
Magnesium chloride	33
Potassium acetate	22
Lithium chloride	12
Potassium hydroxide	9

2.6 Control of testing room atmosphere

Testing laboratories require the atmosphere to be maintained at 65 ± 2% RH and 20 ± 2 °C in order to carry out accurate physical testing of textiles. The temperature is controlled in the usual way with a heater and thermostat, but refrigeration is necessary to lower the temperature when the external temperature is higher than 20 °C as is usually the case in summer. The tolerances allowed on temperature variation are quite difficult to meet. The relative humidity is controlled by a hygrometer which operates either a humidification or a drying plant depending on whether the humidity is above or below the required level. Double glazing and air locks to the doors are usually fitted to the laboratory in order to reduce losses and to help to keep the atmosphere within the tolerance bands. Adequate insulation is necessary on all external surfaces as the high moisture content of the atmosphere can cause serious condensation on cold surfaces. Only large organisations may be able to afford a fully conditioned testing laboratory. If one is not available, testing should be carried out in a room in which ambient conditions are as uniform as possible throughout the year in order to cut down on variations in measurements due to atmospheric variation.

Cabinets that control the atmosphere of a relatively small volume can be obtained commercially. These may be used to condition samples before testing, the actual tests being carried out in a normal atmosphere straight after removal from the conditioned atmosphere. The relative humidity of a small enclosed volume of air, such as a desiccator, may be controlled by the presence of a dish containing a saturated solution of certain salts such as those listed in Table 2.3 [14].

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