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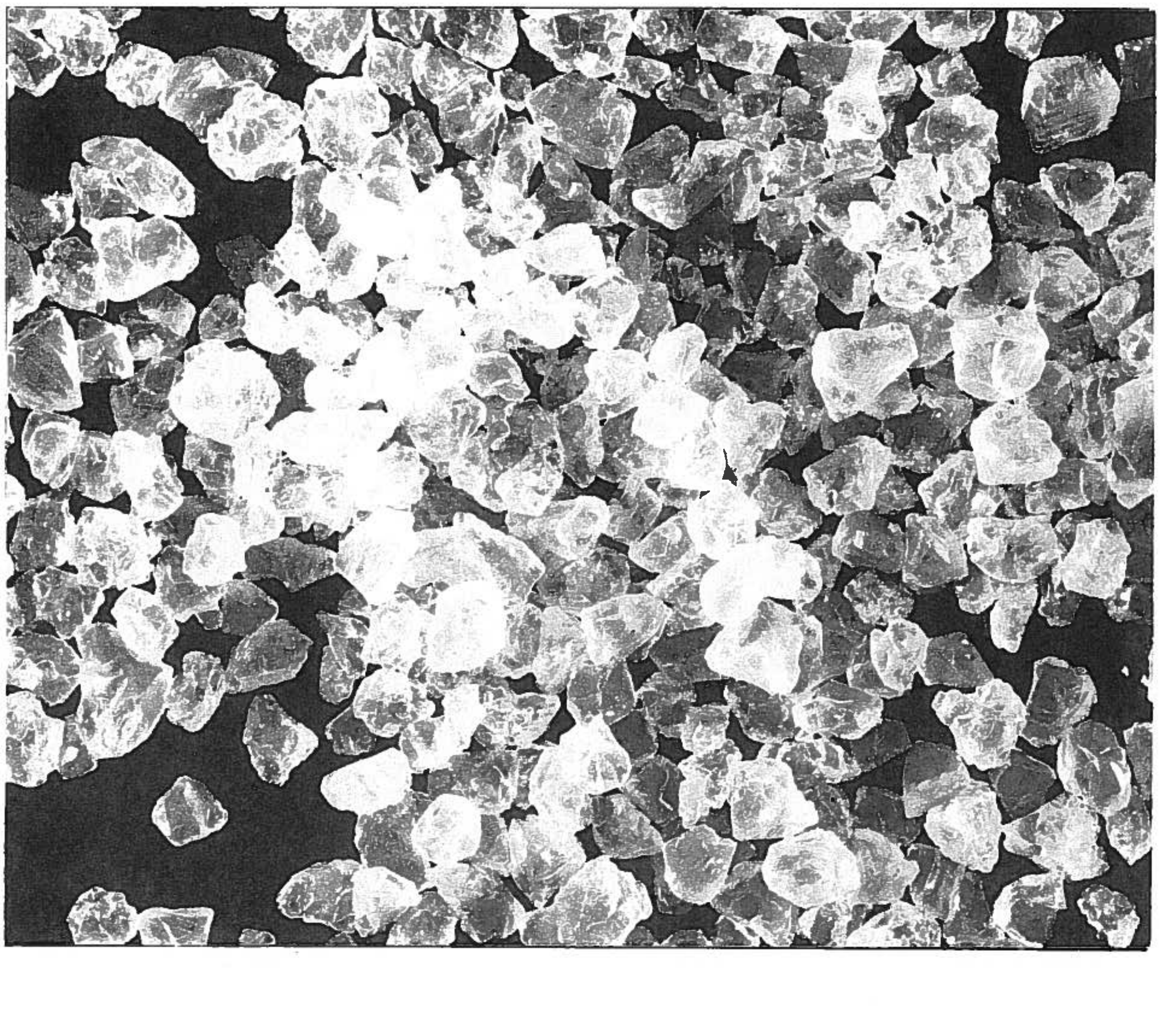
Technical Bulletin 10

Silica Gel



Canada

TECHNICAL BULLETIN NO. 10

Silica Gel

by
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Abstract

The purpose of this technical bulletin is to explain the use of silica gel, how it controls RH, and how it is conditioned for use and maintained. The specific topics dealt with are: the problems of display case leakage, the requirements of a humidity buffering agent and how silica gel fulfils these, the various steps in the process of conditioning silica gel, the positioning of silica gel in the display case, and the maintenance of a silica gel buffered case.

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1. INTRODUCTION

Curators and conservators around the world are aware of the need to maintain their collections under safe, controlled and constant environmental conditions. These conditions include safe light levels, a stable temperature and a constant level of relative humidity (RH). It is the last which is often the most difficult to control. By far the most widely used method of RH control is a display case containing silica gel. A small museum may have one of these cases for the most important object in its collection whereas larger museums often have many.

Although silica gel is widely used in display cases, museum staff do not always understand the procedure for its proper preparation or conditioning, and maintenance. Still more important, they often do not recognize the necessity for these procedures.

Because of its chemical properties, silica gel is suitable both as a drying agent to remove moisture from the air, *and* as a humidity buffering agent to maintain or buffer the RH to a constant level. For either purpose it must be conditioned. For example, if used as a drying agent (e.g., the small packages in packed stereo components), it must first be dried so that it can absorb moisture from the surroundings. For use in museum display cases as a buffering agent, it must be conditioned by the appropriate methods described in this bulletin.

The purpose of this technical bulletin is to explain the use of silica gel, how it controls RH, and how it is conditioned for use and maintained. The specific topics dealt with are: the problems of display case leakage, the requirements of a humidity buffering agent and how silica gel fulfils these, the various steps in the process of conditioning silica gel, the positioning of silica gel in the display case, and the maintenance of a silica gel buffered case. Certain mathematical equations and calculations (necessary for determining the proper amounts of gel and water needed) have been included (see appendix 3). Should a museum lack the necessary equipment (e.g., scales or an oven) to process the silica gel, the nearest high school would probably be able to provide suitable laboratory facilities.

2. DISPLAY CASE LEAKAGE

Before discussing silica gel itself, a few words on case leakage are in order. A museum display case is usually made of glass or Plexiglas on a wooden base. Although well sealed, no museum display case is perfectly airtight. Even a well-designed case will allow some air leakage. The transfer of air and moisture in and out of the case occurs mostly through cracks, and imperfect seams and joints. Consider, for example, a well-designed case conditioned at 50% RH and placed in a room at 15% RH. The RH in the case will slowly drop and eventually reach 15%. A similar change would take place in a house if the furnace were turned off in the winter: the inside temperature would drop slowly. If the house is well sealed and also well insulated, the rate of temperature decrease will be slow. The same is true of a well-sealed case compared with a leaky case. In these situations, RH and temperature reach a point of *equilibrium* with the external environment after a period of time.

The transfer of humidity from inside a case to the outside (or vice versa if outside RH is higher) occurs at an exponential rate, i.e., the process is fast at first, but slows down with time as the RH difference decreases. Figure 1 illustrates how the RH, originally at 50% inside a case in a room at 15% RH, might change with time. The RH starts off at 50% as shown at A, and drops until it almost reaches the 15% of the room at point B after about 24 hours. Another way of describing this change would be to say that the air inside the case has been exchanged for outside air after a certain period of time. This particular case might undergo one air change per day but, in fact, museum cases sometimes undergo several air changes every day. (The use of air change rates is a simplified method of describing the more complicated exponential rate of change, and is often used by engineers when dealing with climate control of buildings.)

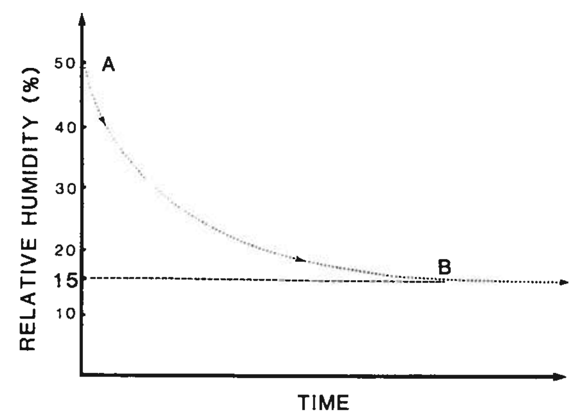


Figure 1: *Graph showing the exponential decrease of relative humidity inside a case, at 50% initially (A), located in a room with an RH of 15%.*

The proper use of sealing compounds, gaskets and tight-fitting access doors can lower the air change rate to about one change every 24 hours. It is difficult to improve on this. Although a good display case which has no other form of protection would minimize those rapid RH fluctuations which last only a few hours, any external RH change lasting longer than a couple of days would result in a similar change inside the case. To illustrate this effect, theoretical humidity conditions inside and outside a display case are shown in figure 2. The two rapid RH fluctuations marked A are not so severe inside the case as outside because the inside reacts more slowly to this change. If the outside RH remains persistently low, as indicated by the section of the curve marked B, the inside RH eventually reaches a similar low level. This situation occurs in many parts of Canada where RH remains low for long periods during the winter. (The reverse applies in summer when the outside RH remains persistently high.)

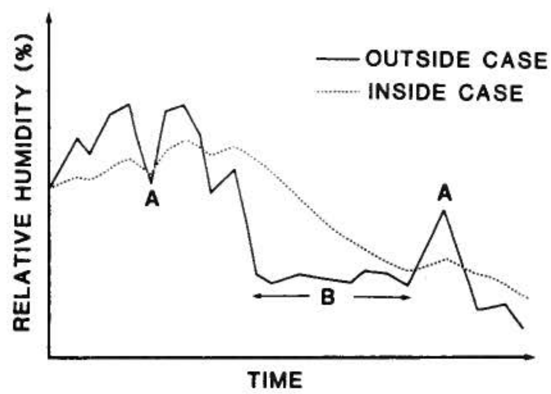


Figure 2: *A well-sealed display case moderates rapid exterior RH fluctuations, but follows the average exterior RH conditions.*

To achieve a further degree of RH control, some means of adding moisture to or removing moisture from the case must be incorporated. Mechanical means would be expensive for a single case. However, passive, non-mechanical techniques are available. The use of a buffer material such as silica gel is the best and most often encountered example.

3. HUMIDITY BUFFERING AGENTS

Webster's New Collegiate Dictionary defines *buffer* as "any of various devices or pieces of materials for reducing shock due to contact". In the field of humidity control, *buffer* takes on a similar meaning: a material or substance used to minimize changes in the relative humidity of a given volume of air which would otherwise occur as a result of outside climatic changes.

Many substances contain a certain quantity of water which is determined by the relative humidity of the surrounding air. For any given RH condition, a substance has a precise and specific moisture content when it is in equilibrium with the air (see appendix 1: Hysteresis and Temperature Effects on EMC vs. RH Curves). The equilibrium moisture content (EMC) of a substance is the ratio of the mass of water it contains to the dry mass of the substance, and is expressed as a percentage. It is usually represented by an EMC vs. RH curve. For each RH condition, a given substance has a corresponding equilibrium moisture content.

Figure 3 illustrates an EMC vs. RH curve for a substance containing 20% water at 50% RH, when it is at equilibrium. If its moisture content were 22% instead of 20% at 50% RH, then it would not be in a state of equilibrium, but would release water into the surrounding air until it had reached the equilibrium point on the curve, that is 20%. Conversely, if the moisture content were 18%, the material would absorb water from the air to reach 20%. This equilibration is the basis of the buffering action of substances such as silica gel; it provides a method by which moisture can be added to a volume of air when it is too dry, or removed when it is too humid. By placing a quantity of buffering material in a case, the internal RH can be controlled to some extent. A complete explanation of this equilibration, and of the variables concerned, is given in appendix 2.

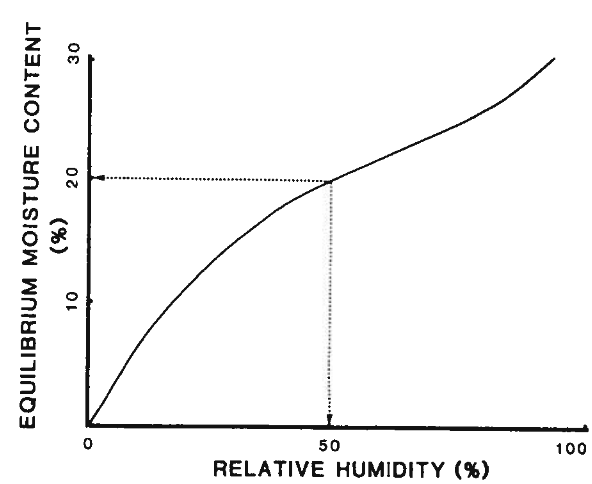


Figure 3: *Typical Equilibrium Moisture Content (EMC) vs. Relative Humidity (RH) curve.*

The moisture-retaining capacity of substances varies considerably so that not all can be used as effective buffers. A good buffering material would have to meet the following requirements:

1. The substance must have a high capacity either to release or to absorb water. (Such materials will have a relatively high moisture content around the desired RH level. That is, the EMC vs. RH curve will have a steep, linear slope near the desired RH so that large EMC changes correspond to lesser RH changes.)

2. The substance must offer a large surface area to allow a rapid rate of buffering.

TABLE 1

Bulk Densities of Various Grades of Silica Gels

Grade	Mesh Size	Bulk Density (kg/L)	Type
01	3-8	0.64	non-indicating
40	6-12	0.63	non-indicating
03	on 8	0.68	non-indicating
41	3-9	0.69	non-indicating
59	3-8	0.36	non-decrepitating
42	6-16	0.67	indicating
407	8-20	0.68	non-indicating
43	14-20	0.70	indicating

3. The substance must not suffer any physical damage when it absorbs and desorbs water.

4. The substance must remain dry to the touch even with a high moisture content.

5. The substance must be easily conditioned and reusable.

4. SILICA GEL

All the above requirements are met by silica gel, which is a porous, granular and non-crystalline form of silica (99.7% silica content). It is chemically inert, non-toxic, non-deliquescent, dimensionally stable and non-corrosive. It is compatible with most materials, with the exception of strong alkalis and hydrofluoric acid.

Over 25 different grades of granular silica gels are commercially available. These vary in particle size, absorption characteristics and purity. Moisture content indicators are added to some types (table 1).

The grades of silica gel mentioned in this technical bulletin (except grade 59) are acceptable for use in display cases. Grade 59 silica gel is a special non-decrepitating type, which will not crack and break up when brought into contact with water, but which has a much reduced efficiency. It should not be used in display cases except in combination with other grades.[1] The rate of absorption/desorption does not vary significantly between those grades listed in table 1 (except grade 59). Some have a special coloured coating which indicates whether the gel is in a dry, activated state (blue colour) or whether it has absorbed water and is no longer a good desiccant (pink colour), thus requiring reactivation. These indicating silica gels have the same buffering properties as an ordinary type of gel.

Although the gel is non-toxic, it can give off a fine silica dust when transferred from one container to another. Therefore, when handling silica gel, the user should wear a dust-filtering mask such as those sold in hardware stores for spray painting.

Silica gel is available from most laboratory equipment and chemicals suppliers. It is important to specify the proper grade and mesh size when ordering. For example, a very fine powdered gel is available for use in chromatography; it should not be used for buffering display cases (figure 4).

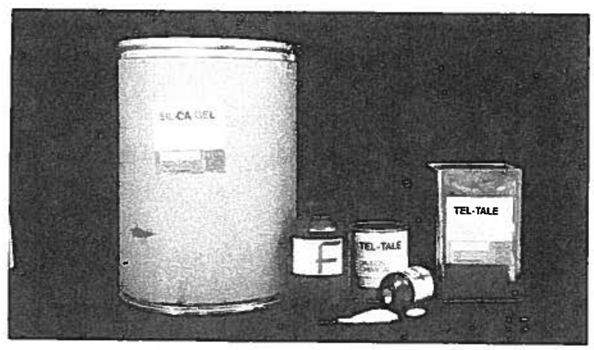


Figure 4: *Silica gel, a granular solid, is available in a variety of container sizes, from 500 g bottles to 70 kg drums.*

[1] Steven Weintraub, "A New Design for a Low Maintenance Silica Gel System for the Control of Relative Humidity in a Sealed Case", in Vienna Congress, *Conservation Within Historic Buildings*, ed. N. S. Brommelle, Garry Thomson and Perry Smith (London: The International Institute for Conservation of Historic and Artistic Works, 1980), 55–57.

Silica gel has an almost indefinite shelf life, therefore, a good supply can be purchased without fear of exceeding its useful life span. The cost of the gel per kilogram varies from one grade to another and depends on the quantity purchased.

Silica gel is mostly used as an industrial desiccant, that is, a drying agent. For this reason it is almost always shipped in a dry, activated state. Placing this dry gel in a display case would result in the complete desiccation of the air and objects inside. *The gel must be conditioned to the desired RH.* The maintenance of a very dry environment for certain metals is the only situation where silica gel could be used as received.

5. CONDITIONING SILICA GEL

Conditioning silica gel entails adding moisture until the gel has reached an equilibrium moisture content corresponding to the desired relative humidity. To maintain a given relative humidity in a display case, the silica gel used must have a moisture content equivalent to its equilibrium moisture content at the specified RH. This value is obtained from the EMC vs. RH curve of that particular grade of gel. Figures 5 and 6 present these curves for eight common grades as measured at the Canadian Conservation Institute. Certain deviations from these curves can be expected from batch to batch, but they are not significant in most situations.

Silica gel is conditioned in four steps: drying the gel, determining the amount required, weighing it, and adding moisture to it.

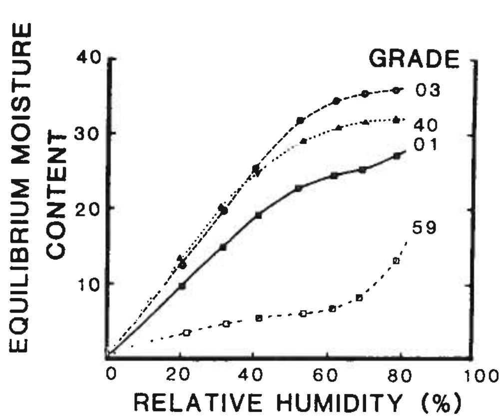


Figure 5: *EMC vs. RH curves for various grades of silica gel.*

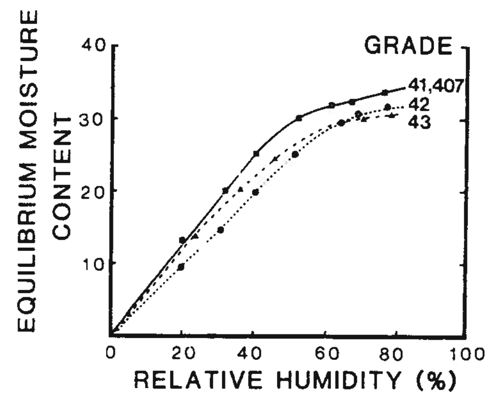


Figure 6: *EMC vs. RH curves for various grades of silica gel.*

5.1 Drying the Silica Gel

The first step in the conditioning is to dry the gel; although shipped in a dry state, it may still contain a small percentage of water. As the exact dry mass is required in many of the calculations, the gel must be dried completely before weighing. Place the silica gel in shallow pans to a depth of about 2 cm, and then heat in an oven (120°C) for 12 hours or more (figure 7). Kitchen ovens are quite suitable; incubators cannot be used because they do not usually provide sufficiently high temperatures. Microwave ovens have not been tested, but are probably not suitable. After the gel is dry, place it immediately in metal containers, and seal tightly (figure 8). (Most hardware stores can provide new paint containers which are excellent for storage.) Allow the gel to cool for a few hours before weighing.

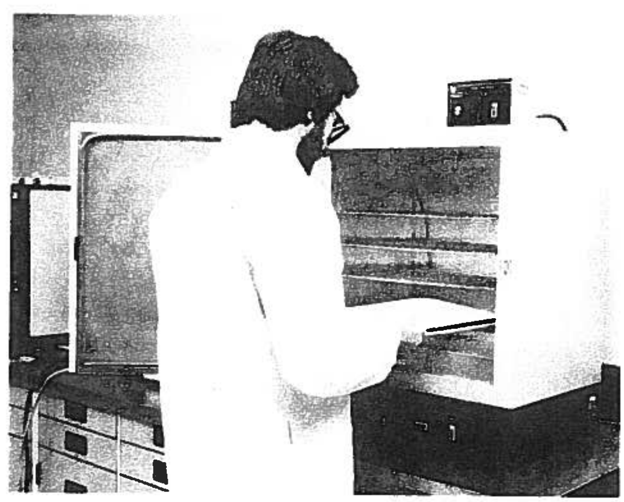


Figure 7: *Silica gel is dried by heating in an oven at 120°C for 12 hours.*

Figure 8: *Hot silica gel is placed in a metal container which is then sealed.*

5.2 Amount of Gel Required

The quantity of conditioned silica gel in a case is very important and will determine the effectiveness of a case to maintain the proper RH level for extended periods of time. Too little silica gel will not have the required capacity to buffer long-term variations in RH. Too much will require excessive space in the case and will add to the cost of the system. For a reasonably well sealed case, 20 kg of conditioned silica gel should be used for every cubic metre.[2] If this recommendation is followed, the RH inside the case can be maintained in the range of 35% to 65% RH even during very dry or very humid conditions. As an example, consider a small display case which needs to be maintained at 50% RH. The total volume of the empty case, including the space underneath the false bottom (see section 6), is 0.3 m^3.

Calculate the approximate mass of conditioned gel required, in kilograms, by multiplying the case volume in cubic metres by 20. Thus, for the small case this would be 20 × 0.3 m^3 or 6.0 kg. Next, determine the equivalent EMC of the particular grade of silica gel being used (assume grade 01) at the required 50% RH. From figure 5, grade 01 gel has an EMC of 23% at 50% RH. With the following formula, it is now possible to calculate the required amount of dry gel:

Mass of dry gel

$$= \frac{\text{mass of conditioned gel (kg)}}{1 + \text{EMC}}$$

$$= \frac{6.0}{1 + 0.23}$$

$$= 4.9 \text{ kg}$$

Once the exact mass of silica gel required is known, the actual volume occupied can be calculated by using the bulk densities presented in table 1. For example, the volume occupied by 4.9 kg of grade 40 gel is calculated as follows:

Volume

$$= \frac{\text{mass of gel (kg)}}{\text{density of gel (kg/L)}}$$

$$= \frac{4.9}{0.63}$$

$$= 7.8 \text{ L}$$

5.3 Weighing the Silica Gel

For conditioning, place the cool dry gel in a screen-tray assembly (figure 9) or, alternatively, into bags made from extremely permeable and heat-resistant material, such as silk-screening polyester (figure 10). The size of the bags depends on the case dimensions and the quantity of gel. If loose gel is being conditioned, weigh the empty screen-tray assembly before starting the procedure. This eliminates transferring the gel from the assembly to another container for subsequent weighing. As bags make it easier both to handle and to reuse the gel, the instructions which follow are based on gel contained in a bag.

Weigh the empty bag and record its mass on an attached label (figure 11). Pour the cooled, dried silica gel into the bag and weigh it immediately. (If a laboratory scale is not available, a postal or baby scale may be used.) Close the bag by stitching. Clearly indicate the dry mass on the label. The bagged silica gel may be reused almost indefinitely without the need for reactivation in the oven to calculate the dry mass.

[2] Garry Thomson, "Stabilization of RH in Exhibition Cases: Hygrometric Half-Time", in *Studies in Conservation*, ed. John S. Mills, vols. 21–22 (London: The International Institute for Conservation of Historic and Artistic Works, 1977), 85–102.

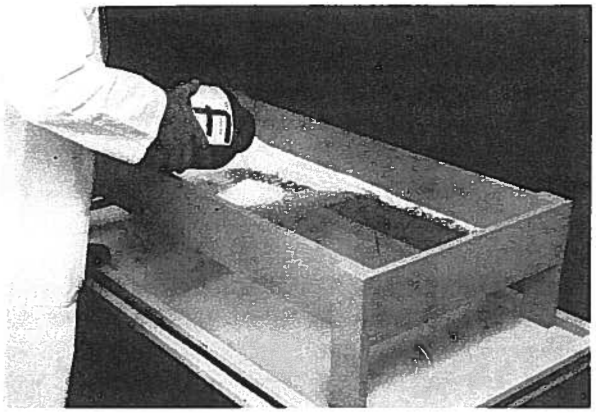


Figure 9: *A known amount of dry silica gel is poured into the screen-tray assembly for conditioning. The assembly has been preweighed so that the silica gel need not be removed to monitor its mass. The whole is then weighed and the mass of the silica gel is calculated by subtracting the mass of the assembly from the total mass.*

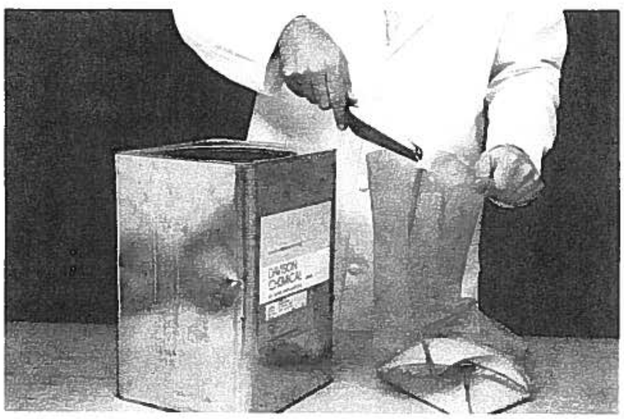


Figure 10: *Dry silica gel is poured into a preweighed bag and the total mass is recorded. The bag is then sealed for conditioning.*

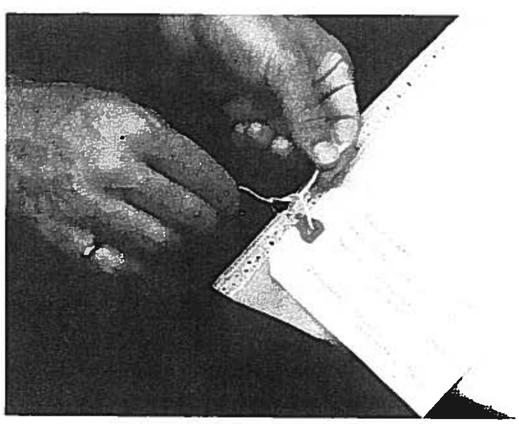


Figure 11: *The label attached to the silica gel bag indicates the mass of the empty bag, the dry silica gel and the total mass.*

5.4 Adding Moisture to Gel

The next step in the conditioning process is to add moisture to the silica gel until its moisture content reaches the required level. NEVER ADD WATER DIRECTLY TO SILICA GEL.

There are several ways to add moisture to silica gel: with a commercial environmental chamber, with salt solutions or water in a conditioning chamber, by a dry mixture method, or by a forced air method. With the first method, place the gel (loose or in bags) in an environmental chamber maintained at the desired RH. Weigh the gel every two or three days until the mass has stopped changing. A minimum of one week is usually required to attain complete absorption of the moisture. This is a very convenient method, but also the most expensive. Commercial environmental chambers are costly.

The next two methods (using either salt solutions or water in a conditioning chamber) are much cheaper and just as effective. They both require the construction of a reasonably well sealed conditioning chamber made of a suitable material such as Plexiglas. The base is made of plywood covered with two coats of good quality latex paint. On this rests a shallow conditioning pan which covers at least 50% of the base area. A screen-tray assembly holds the silica gel over the conditioning pan (figures 9 and 12). Weather stripping between the base and the Plexiglas is an adequate seal against leakage. It is often useful to have a hygrometer inside the conditioning chamber to monitor the RH.

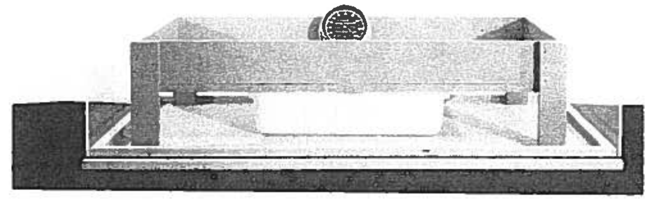


Figure 12: *The conditioning installation. The hygrometer indicates the RH inside the chamber.*

Salt Solutions in Conditioning Chamber

With this method, saturated salt solutions are used to achieve the required humidity in the conditioning chamber; the silica gel is conditioned to maintain RH at the same level as that above the salt solution. Table 2 lists several of these compounds and the corresponding percentage relative humidity maintained by each salt.

TABLE 2

Compounds and Corresponding Percentage Relative Humidity
Above Saturated Solution

Temperature (°C)	RELATIVE HUMIDITY (%)					
	$LiCl \bullet H_2O$	$MgCl_2 \bullet 6H_2O$	$Na_2Cr_2O_7 \bullet 2H_2O$	$Mg(NO_3)_2 \bullet 6H_2O$	$NaCl$	$Ca(NO_3)_2 \bullet 4H_2O$
10	13.3	34.2	57.9	57.8	75.2	
15	12.8	33.9	56.6	56.3	75.3	
20*	12.4	33.6	55.2	54.9	75.5	55.0
25	12.0	33.2	53.8	53.4	75.8	51.0
30	11.8	32.8	52.5	52.0	75.6	

*approximate room temperature

Approximate quantity of salt to be added to one litre of water to make a saturated solution at room temperature:

$LiCl \bullet H_2O$–(lithium chloride monohydrate)	0.85 kg ($LiCl \bullet H_2O$)
$MgCl_2 \bullet 6H_2O$–(magnesium chloride hexahydrate)	3.7 kg ($MgCl_2 \bullet 6H_2O$)
$Na_2Cr_2O_7 \bullet 2H_2O$–(sodium dichromate dihydrate)	2.9 kg ($Na_2Cr_2O_7 \bullet 2H_2O$)
$Mg(NO_3)_2 \bullet 6H_2O$–(magnesium nitrate hexahydrate)	2.5 kg ($Mg(NO_3)_2 \bullet 6H_2O$)
$NaCl$–(sodium chloride)	0.38 kg ($NaCl$)
$Ca(NO_3)_2 \bullet 4H_2O$–(calcium nitrate tetrahydrate)	6.5 kg ($Ca(NO_3)_2 \bullet 4H_2O$)

Choose a compound that will maintain humidity closest to the percentage desired. In the example of a small case to be maintained at 50% RH, hydrated magnesium nitrate [$Mg(NO_3)_2 \bullet 6H_2O$] with 54.9% RH at room temperature (20°C), would give an RH closest to that required. It is not necessary with this method to calculate the amount of water absorbed by the gel during conditioning.

Prepare the saturated salt solution in the following way. To the required quantity of water, slowly add the salt while stirring constantly until no more will dissolve (figure 13). Exercise caution when adding the salt because, in some cases, the process will give off heat and the solution will become quite warm. Let it stand for an hour, and then add more salt until crystals remain visible. Keep the solution in a closed glass container until needed.

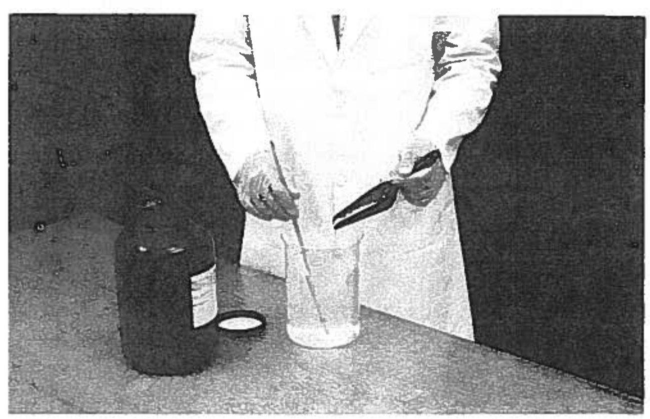


Figure 13: *Preparing a saturated salt solution. A thermometer, used to monitor the temperature of the solution, is clamped to the side of the beaker.*

Fill the conditioning pan to a depth of about 2 cm. (The solution in the pan must contain some undissolved crystals.) Within the conditioning chamber, place the pan of saturated salt solution on the base, and over it the screen-tray assembly which contains the silica gel, either loose or in bags. Seal the chamber and allow the gel to equilibrate over a period of at least one week. Weigh the silica gel to confirm the completion of the conditioning process, i.e., when the mass stops changing. As the gel absorbs the water lost by the saturated solution, it may be necessary to add small quantities of water to the salt solution to prevent it from going completely dry. However, undissolved crystals must always be present in the salt solution.

Water in Conditioning Chamber

This method is less expensive than the saturated salt solution method. To condition silica gel for the same small case previously described, take 4.9 kg of dry gel, either loose or in a bag. For this illustration, a bag (weighing 15 g when empty) will be used. The amount of moisture which must be added to the gel is calculated as follows:

Mass of water required
= EMC × mass of dry silica gel (kg)
= 0.23 × 4.9
= 1.1 kg (equivalent to 1.1 L of water)

Because the mass of the bag is less than about 1% of the mass of the gel to be enclosed, it can be ignored in subsequent calculations. Therefore, on completion of conditioning, the total mass of bagged conditioned gel should be:

4.9 kg (gel) + 1.1 kg (water) = 6.0 kg

Using the conditioning chamber already described, place 1.1 L of water (instead of a salt solution) in the pan underneath the screen-tray assembly containing the bagged silica gel, and seal the chamber. After the water in the pan has evaporated completely (which may take at least a week), remove the silica gel and weigh it. (A small fan placed beside the pan of water will accelerate evaporation, and complete evaporation may take place within a day instead of a week.) The final mass should be 6.0 kg. Because of air leakage from the case, it is improbable that all the water was absorbed by the gel. If, for example, the mass of the gel reached 5.9 kg, then a further 0.2 kg (0.2 L) of water is required. Repeat the procedure using only 0.2 kg of water in the pan. The process should be continued until the final mass is within 1% of the desired mass, or as close as possible depending upon the weighing system available. In the example, this would be 6.0 ± 0.06 kg (i.e., between approximately 5.9 kg and 6.1 kg).

To verify the calculations and to ensure that the procedure has been well followed, measure the RH in the chamber containing the conditioned silica gel. Use a motor-blown psychrometer or a thermohygrograph or hygrometer (with careful attention to the calibration of these instruments). Normally, the difference between calculated RH and actual RH is minimal. Batch to batch variations in EMC values may lead to slightly larger differences. If the actual RH disagrees with the calculated RH by much more than 10%, it is quite possible that an error has occurred in weighing or in the calculation.

Dry Mixture Method

As many museum artifacts require a relative humidity of 50%, an ample supply of silica gel already conditioned to 50% RH should be readily available. The dry mixture method involves mixing gel conditioned to 50% RH with dry silica gel in a closed container until equilibrium is reached. The proportions of gel used in this mixture allow for adjusting the final RH from 0.5% up to 50%.

For example, suppose 10.0 kg of conditioned gel is required to maintain 30% RH in a small case, and that a good supply of grade 01 gel conditioned to 50% RH is available (EMC = 23%). At 30% RH, the EMC of grade 01 gel is 15% (from figure 5). Calculate the total dry mass of gel required as follows:

Mass of dry gel

$$= \frac{\text{mass of conditioned gel (kg)}}{1 + \text{EMC (at the desired RH)}}$$

$$= \frac{10.0}{1 + 0.15}$$

$$= 8.7 \text{ kg}$$

The mass of water required is then:
10.0 kg − 8.7 kg = 1.3 kg
(or alternatively, 15% × 8.7 kg = 1.3 kg).

This water is supplied by the gel conditioned to 50% RH. The mass of gel required to supply this amount of water is calculated using the following equation (EMC is 23% for gel conditioned to 50% RH):

Mass of gel conditioned to 50%

$$= \frac{\text{(mass of water)} \times (1 + \text{EMC})}{\text{EMC}}$$

$$= \frac{1.3 \times (1 + 0.23)}{0.23}$$

$$= 7.0 \text{ kg}$$

Place into a container 7.0 kg of silica gel conditioned to 50% RH, and add enough dry gel to make 10.0 kg, i.e., 3.0 kg. (The large metal containers in which the silica gel is normally shipped are excellent for this purpose.) Mix the gels together and close the container. Moisture will transfer from the conditioned gel to the dry gel and finally reach equilibrium. A week should be sufficient time to allow proper equilibration. The final product is 10.0 kg of gel with an EMC of 15% and an equivalent RH of 30%.

Forced Air Method

The conditioning methods described so far in this bulletin are suitable for small to moderate quantities of silica gel. When these same methods are used for large amounts of gel (greater than about 50 kg) the necessary installations can be somewhat cumbersome and the conditioning will take longer. This is especially true if only a small conditioning chamber is available. It would be impractical to spread out 1000 kg of gel a few centimetres thick on screens or trays.

A rapid conditioning method suitable for large quantities of silica gel has recently been developed and tested at the Canadian Conservation Institute. The method is well suited for treating drums of gel and has the advantage of not requiring removal of the gel from its original container. The method involves the forced passage through the silica gel of room air with the desired RH.

First, remove the drum cover and replace it with screening which is securely held in place by the original retaining ring (figure 14). Then, turn the drum over and place it on wooden supports to allow for access of air to the screen and through the gel (figure 15). The objective now is to create suction from the top of the drum. To achieve this, cut an opening in the top (originally the bottom) of the drum to allow the insertion of a large-diameter pipe or hose (for example, drain pipes, duct pipes, or flexible exhaust hose for clothes driers). Seal the connection with tape, and connect the other end of the pipe to the suction side of a large high-pressure ventilation fan, e.g., a 750 W blower capable of 0.5 m³/s at 15 cm of water.

An alternative method for creating the required suction is to use a clean wet-dry vacuum cleaner (with the filter removed). Either connect it to the drum by its own hose (with a screen over the end of the hose to prevent particles being sucked in), or remove the blower part from the container and insert it into the drum without any pipe or hose. For either method, the hose should be positioned at a minimum distance of 10 cm from the surface of the silica gel.

Figure 14: *The cover is replaced with aluminum screening which is held in place by the original retaining ring.*

Figure 15: *The drum is inverted and placed over spacers. In what was originally the bottom of the drum, a hole is cut to the size of the blower section of a wet-dry vacuum cleaner. The blower section is then inserted into this hole and seams are well sealed.*

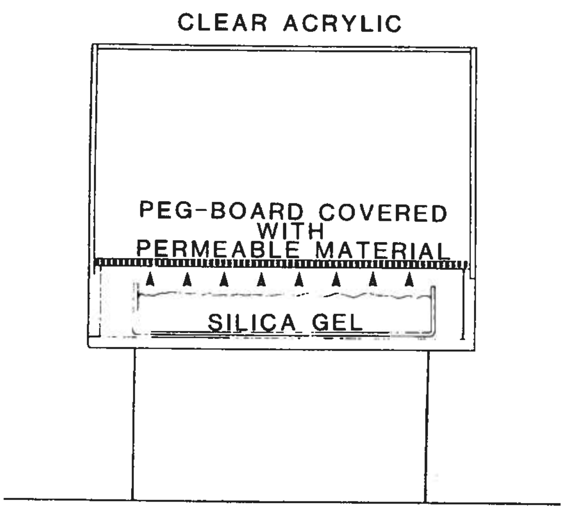
Whether a ventilation fan or a vacuum cleaner is used, the length of pipe or hose should be free of any holes or unsealed seams and joints. Any leak between the drum and the suction device will increase conditioning time. With a relatively high-capacity suction source, conditioning can be completed in as little as three to four days. If a very large blower is used, several drums of silica gel can be conditioned simultaneously by connecting them in parallel. With a vacuum cleaner only one drum can be conditioned at a time.

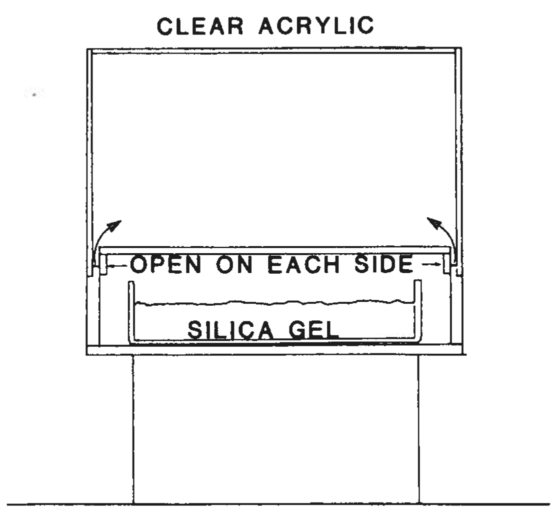
By any of these methods the silica gel will invariably be conditioned to room RH. If the latter is too low or too high, it can be adjusted by using portable humidifiers or dehumidifiers. For optimum results, the conditioning should be carried out when the room RH is closest to the desired levels.

To monitor the progress of the conditioning procedure, place the drum on a scale (a bathroom scale is suitable) and monitor its mass. The procedure is completed when the mass has reached a maximum and has remained constant for more than a day. Completion time will depend on the capacity of the suction source and the degree of air leakage. For example, if 0.033 m^3/s of air is drawn through, the gel will be about 99% conditioned after four days.

6. POSITIONING SILICA GEL IN A DISPLAY CASE

Normally, a tray containing the gel rests on the bottom of the case, under a partial false bottom. Although it is not the purpose of this technical bulletin to discuss specific case designs, it is important that the construction of the case allow the air in the case to have free access to the gel (figures 16a and 16b).





Figures 16a and 16b: *Examples of suitable case designs which allow transfer of moisture from the silica gel to the upper part of the case.*

Whereas simple diffusion of moisture in the air should be sufficient to eliminate non-uniformity of RH or microclimates, in very large or tall cases the use of a small fan may accelerate the diffusion process. Figure 17 shows how to incorporate one into the design of a case. A suitable fan would be relatively quiet and give off little heat; many satisfactory types are sold in electronics stores for cooling small computers.

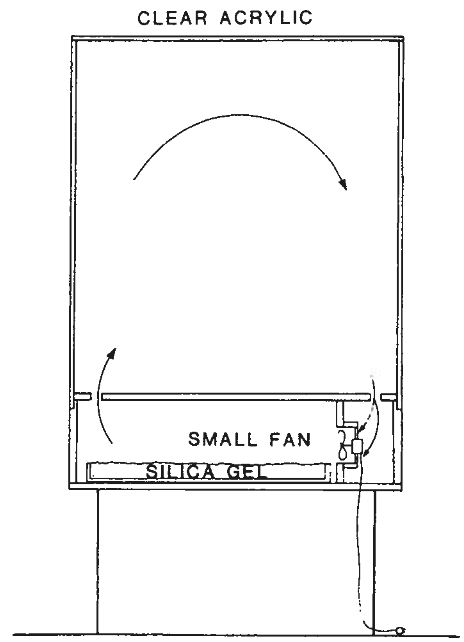


Figure 17: *A small fan improves the circulation in very large or tall cases.*

It should be noted that display case lighting will cause the temperature inside a display case to rise, thereby reducing the RH. This effect can only be controlled by reducing the lighting level, and should be considered when the case is being designed.

7. MAINTAINING THE RH OF A SILICA GEL BUFFERED CASE

7.1 Monitoring the Case

Even with the recommended quantity of silica gel in a well-designed, low-leakage display case, the relative humidity may slowly decrease in winter and increase in summer within a range of 35%–65% RH. This range may be even greater when cases have high leakage rates, are often opened, or when the RH conditions in the museum are extremely severe. To determine the exact fluctuations in RH, install a hygrometer or thermohygrograph inside the case. Careful attention must be paid to the calibration of these instruments; frequent checks of their accuracy are advised. An alternative method of measuring the RH is to insert the sensor of an electronic hygrometer into a small port or opening in the case. The port should be kept closed when not in use.

7.2 Reconditioning Used Gel

When the RH inside the case has changed more than is acceptable (as determined by the sensitivity of the artifacts displayed in the case), then carry out one of the following maintenance procedures: replacement of the used gel with conditioned gel (either new or recycled), addition of moisture by an *in situ* method, or removal of moisture by an *in situ* method.

Replacing the Gel

For stringent requirements, or for cases with high leakage rates, it may be necessary occasionally to replace the used gel with newly conditioned gel.

Recycling the Gel

If the used gel is in bags, it is easy to determine by weighing whether moisture must be added or removed to bring it to the desired EMC. If its moisture content has decreased, the difference in mass will determine the amount of water to be replaced. On the other hand, used silica gel which has a higher EMC than the required value should be partially dried. Use of a lower temperature (i.e., approximately 60°C) than was needed for the first conditioning will ensure that the fabric of the bag will not be damaged by heat. Complete reactivation is not necessary, as long as the mass of the bagged gel is below the desired total mass. In a previous example, the final desired mass was 6.0 kg. If the mass of the used gel has now dropped to say 5.5 kg, then only 0.5 kg (0.5 L) of water is needed in the conditioning tray. The procedure is then continued until the final mass reaches the desired 6.0 kg.

Adding Moisture by an in situ *Method*

This *in situ* method requires using a hygrometer inside the case, although an access port through which a sensor may be introduced periodically is acceptable. Moisture is introduced into the case by means of a small container of water placed within the tray (figure 18). Localized high humidity levels near the artifacts are prevented by a partial false bottom over the tray and the water. For further RH control, a Plexiglas cover with several small holes (1 cm in diameter) is placed over the water container (figure 19). An alternative cover design, illustrated by figures 20 and 21, offers the advantage of varying the rate of evaporation by means of a device controlled from outside the case. This involves a fixed Plexiglas plate in which a triangular-shaped hole is cut. A second plate, of sufficient size to cover the hole, is laid over the first and held in place by sliders. The plate is slid across by using a dowel and wheel (or string and pulley) assembly to uncover the triangular opening. By this means a much finer control is achieved over moisture release and absorption.

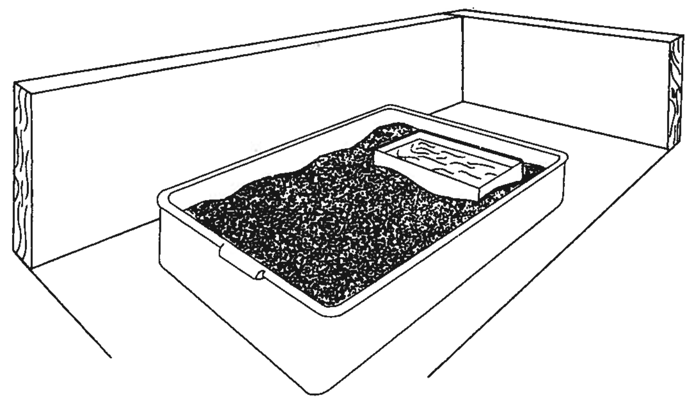


Figure 18: *A small container of water is placed in the tray to introduce moisture into the case.*

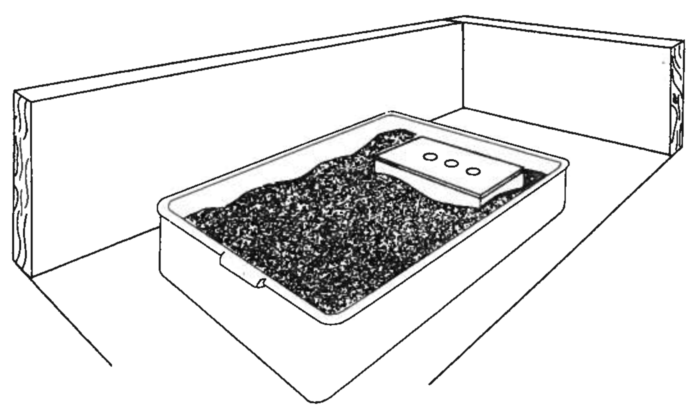


Figure 19: *For further RH control, a Plexiglas cover with several small holes is placed over the water container.*

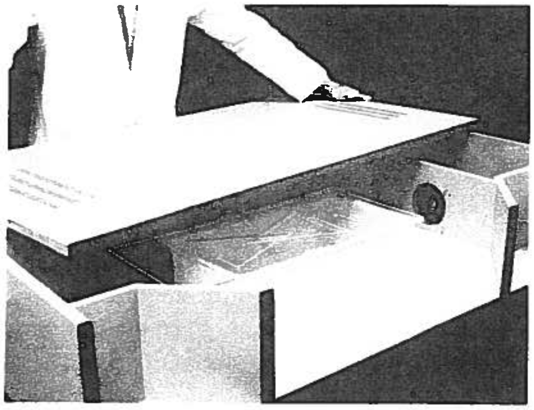


Figure 20: *A Plexiglas cover will control the release of water during* in situ *reconditioning. The bottom piece, covering the whole container, has a large triangular opening. The top piece is slid across to uncover the opening as required.*

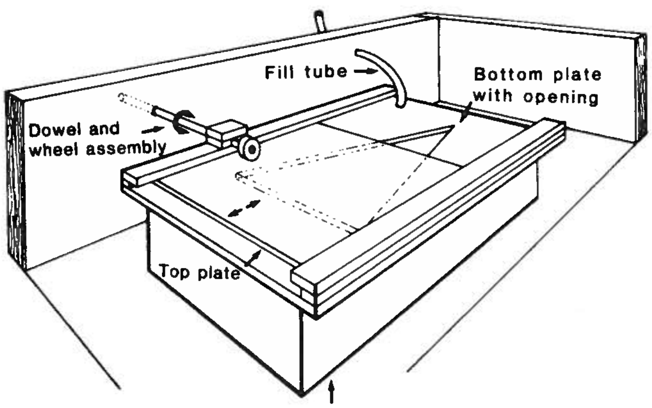


Figure 21: *A dowel and wheel assembly is used to slide the plate across.*

This *in situ* procedure should be undertaken before the RH has changed by more than 10% from the original set point. It is possible that the RH in the small example display case, originally stabilized at 50% with conditioned silica gel, will begin to drop slowly during the dry winter months. After three weeks, the RH might have dropped to 42%, and the EMC of the gel would be 20% (from the EMC vs. RH curve). The quantity of water lost can be calculated easily using the following formula:[3]

Mass of water lost
= (original EMC − new EMC) × dry mass (kg)
= (0.23 − 0.20) × 5.0
= 0.15 kg (equivalent to 0.15 L of water)

[3] This takes into account the water lost by the silica gel only; it does not include the water lost by the artifacts themselves and by the materials making up the case. The last two quantities are difficult to calculate and, for simplicity, have been omitted.

If the conditioned mass is known, the dry mass can be calculated using the equation shown earlier:

$$\text{Mass of dry gel} = \frac{\text{mass of conditioned gel}}{1 + \text{EMC}}$$

In the example, the conditioned gel lost about 0.15 L of water in three weeks. To regenerate this moisture, fill the small container with 0.15 L of water. The rate at which the water evaporates, and is then absorbed by the silica gel, depends mainly on the area of the openings in the water container. At first, stopper all holes except for one or two. If the RH does not increase, open more holes. Once the number of openings necessary for a given case is determined, this information is noted as it will not change significantly for that case in future *in situ* reconditionings. (A rate of increase of about 1% or 2% RH per day is acceptable.)

Removing Moisture by an in situ *Method*

In summer, humidity is normally above 50% and the gel's EMC increases. To regenerate the gel, water must be removed. This can be done by placing the proper amount of dry, activated silica gel in the small container within the tray. To calculate the precise amount of dry gel to be added, one must know the mass of water already absorbed. This can be determined either by weighing the gel or by using the following equation:

Mass of water gained
= (new EMC − original EMC) × mass of original dry gel

The mass of dry silica gel to be added is then calculated using this equation:

$$\text{Mass of dry gel to be added} = \frac{\text{mass of water gained}}{\text{original EMC}}$$

If, for example, the silica gel has absorbed 0.25 kg of water, then the mass of dry gel to be added to restore 50% RH in the case is:

$$\text{Mass of dry gel} = \frac{0.25}{0.23} = 1.1 \text{ kg}$$

APPENDIX 1: Hysteresis and Temperature Effects on EMC vs. RH Curves

A substance will have a precise and specific equilibrium moisture content at a given relative humidity; this is described by its EMC vs. RH curve (figure 3).

For simplicity, two factors have not been discussed in this text: temperature and hysteresis. The EMC vs. RH curve will change at different temperatures. Curves given in this bulletin are for room temperature conditions. Although the shape of the curve remains essentially the same, its position on the graph changes with temperature changes. Thus a substance, whose EMC is 20% at 50% RH and 20°C, may contain only 18% moisture at 50% RH and 30°C. Normally, temperature effects are small. For wood, the shift is about 1% EMC for each 10°C change in temperature. For silica gel, temperature effects are negligible, i.e., less than 1% for a 50°C change in temperature.

Hysteresis is the dependence of the state of a system on its previous history. Thus a substance might have an equilibrium moisture content of 20% at an RH of 50% if it has been previously subjected to very low RH, and yet it might contain 22% moisture at 50% RH if it has been previously exposed to very humid conditions. Hysteresis effects of a few per cent are common. Curves for silica gel given in figures 5 and 6 are for absorption only, in that they represent values obtained when the silica gel is brought from dry to moist conditions. As conditioning of the silica gel usually follows this process (dry to moist) only the absorption curves are required for the calculations.

APPENDIX 2: Explanation of the Buffering Process

Figure 22 shows an enlargement of the EMC vs. RH curve near 50% RH.

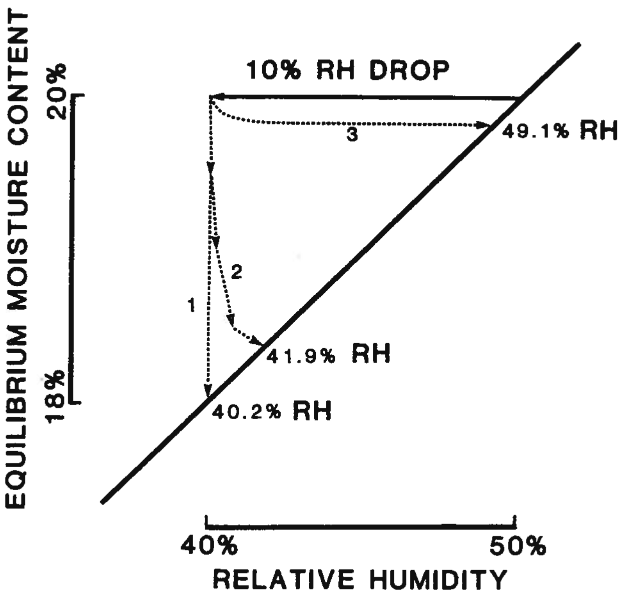


Figure 22: *Enlargement of EMC vs. RH curve for theoretical buffering material.*

Consider 1 kg of a buffering material placed in a large, sealed room of 500 m³. The RH in the room is 50.0%, and the moisture content of the material is 20.0% and in equilibrium. Imagine that the RH in the room is instantaneously lowered to 40.0% as shown by the solid line in figure 22. The material is no longer in equilibrium; in order to reach the new equilibrium moisture content of 18.0%, it must release 2.0% moisture or 20 g of water to the air as indicated by the first dotted line. This would effectively increase the room RH which can be calculated easily by using the following method.

At 20°C, 500 m³ volume of air contains 8.56 kg of water at saturation point (i.e., 100% RH). Relative humidity at a certain temperature is defined as:

$$\text{RH (\%)} = \frac{\text{absolute humidity of sample air}}{\text{absolute humidity of saturated air}} \times 100$$

From this, the original water content (absolute humidity or W) of the air can be calculated as follows:

$$40 = \frac{\text{W (sample air)}}{8.56} \times 100$$

$$\text{W (sample air)} = 0.40 \times 8.56 \text{ kg} = 3.42 \text{ kg of water}$$

Because of the addition of 20 g of water to the air, it now contains 3.44 kg of water and the new RH can be calculated:

$$\text{RH} = \frac{3.44}{8.56} = 0.402 = 40.2\%$$

In essence, the material has buffered a 10.0% RH change to only 9.8%. Because the size of the room is extremely large, the buffering action is very small.

In this example, the material releases its water gradually and each small amount of water released, in itself, affects the room RH. As the room RH changes, so does the equilibrium moisture content which the material needs to reach. As a result, a little less than the full 20 g of water was released as, at 40.2% RH, the EMC of that material is not 18.0%, but actually 18.04%. It is very important to understand this effect because, although small in this case, it will substantially affect the results of the next two examples. For simplicity, moisture content will be calculated on a total mass basis rather than on a dry mass basis as is normally the case.

Consider the same 1 kg of material (as in the first example) placed in a smaller room of 50 m³ with all other conditions being the same. Again, the material must release 2.0% moisture to reach equilibrium. Using the above equation, calculation of the original water content of the air determines that it is 342 g (saturation is 856 g). The release of water is gradual as is the effect on RH and the resulting new EMC. Assume that after a short period of time 5 g of water (0.5% of the total mass of water) is released. The RH in the small room changes to:

$$\text{RH} = \frac{342 + 5}{856} = 0.405 = 40.5\%$$

Thus a new EMC is established and the dotted line (2) in figure 22 deviates slightly to the right to indicate this new condition. A further 5 g of water is released and the RH rises to 41.1%. The EMC at this RH is 18.2%. Again 5 g of water is released amounting to a total of 15 g. The RH has now increased to 41.7% and the equivalent EMC is 18.3%. The actual moisture content of the material is only slightly higher at 18.5%. The release of a final 1.3 g increases the RH to 41.9% with an equivalent EMC of 18.4%. After the material has released a total of 16.3 g of water, its actual moisture content is 18.4% and it is in equilibrium with the air. As the initial 10.0% drop in RH is now reduced to 8.1%, one can begin to see how, with the help of a buffering substance, the equilibrium RH is achieved.

It is important to note that the ratio of the size of the room to the quantity of buffering material determines the extent of buffering (as has been shown by the previous two examples). In the next example, the volume of air has been reduced to that of a 1 m^3 display case. Again the RH is instantaneously lowered to 40.0% and the buffering material needs to release 20 g of water to achieve the new state of equilibrium. It is now obvious that the released water will have a significant effect on the RH in the case.

At 20°C, 1 m^3 of saturated air (100% RH) contains 17.1 g of water and, at 40.0% RH, it contains 6.85 g of water. Consider now the release of water in small steps of 2 g. Table 3 summarizes the progress of change in actual moisture content, the quantity of water released, the relative humidity in the case, and the new equilibrium moisture content as illustrated by the third dotted line in figure 22.

By releasing only 1.6 g of water, the material was capable of buffering an initial 10.0% drop in RH to a much smaller change of 0.9%. Its moisture content dropped by only 0.16% to reach the new equilibrium. It would still have sufficient capacity to buffer further changes.

In practice, the humidity in a case changes slowly and gradually, not by steps of 10%. However, the process is similar but on a much smaller scale, and the end result is the same.

From the preceding series of examples, it is clear that the quantity of buffering material determines the extent of the buffering of a given volume of air, and that the actual moisture content of the material must be relatively high to release sufficient water to the air. This is demonstrated by the steep slope of the EMC vs. RH curve at or near the desired humidity level. The same concepts of buffering apply when the humidity is raised above the equilibrium point, except that the water is absorbed by the buffering material rather than being released from it.

TABLE 3

Predicted EMC and RH Values from Buffering Process
Presented in Appendix 2

Total Water Released	Actual Moisture Content (%)	Case RH (%)	New EMC Corresponding to Case RH (%)
0.0	20.00	40.0	18.00
0.2	19.98	41.2	18.23
0.4	19.96	42.3	18.46
0.6	19.94	43.5	18.70
0.8	19.92	44.7	18.94
1.0	19.90	45.9	19.18
1.2	19.88	47.1	19.42
1.4	19.86	48.2	19.64
1.5	19.85	48.8	19.76
1.6	19.84	49.1	19.84

APPENDIX 3: Examples of Calculations

The following examples of the various calculations are presented to explain further the procedures described in the text.

Determining the Case Volume

Consider, as an example, a display case measuring 0.61 m × 1.22 m × 1.83 m (this includes the space under the false bottom).

Volume of the case
= 0.61 m × 1.22 m × 1.83 m
= 1.36 m^3

The requirement is to maintain 50% relative humidity (RH) inside this case using grade 01 silica gel which has been previously dried overnight in an oven and stored in a well-sealed container.

Amount of Gel Required

Mass of conditioned gel required for this display case (ignoring the volume occupied by the objects displayed):

Mass = volume (m^3) × 20 kg/m^3
= 1.36 × 20
= 27.2 kg

From figure 5, the equivalent equilibrium moisture content (EMC) of grade 01 silica gel is 23% for 50% RH.

Mass of *dry* silica gel needed:

$$\text{Mass} = \frac{\text{conditioned mass (kg)}}{1 + \text{EMC}}$$

$$= \frac{27.2}{1 + 0.23}$$

$$= \frac{27.2}{1.23}$$

= 22.1 kg

Adding Moisture to Silica Gel

Mass of water to be added
= EMC × dry mass (kg)
= 0.23 × 22.1
= 5.1 kg (equivalent to 5.1 L of water)

Another way of calculating the mass of water needed is to subtract the dry mass from the conditioned mass:

Mass of water to be added
= 27.2 − 22.1
= 5.1 kg (equivalent to 5.1 L of water)

The silica gel is easier to handle when contained in bags (section 5.3). However, if loose gel is being conditioned, to eliminate transferring the silica gel from the screen-tray assembly to another container for weighing, weigh the empty assembly before starting any of the procedures. Thus, the assembly and the gel can be weighed together and the mass of the screen-tray assembly is subtracted from the total mass to give the mass of gel only.

Place 22.1 kg of dry gel on the screen-tray assembly inside a conditioning chamber incorporating a small fan, and pour 5.1 kg (or L) of water into the pan beneath. Seal the chamber. After one day, all the water has evaporated and the mass of the silica gel has reached 26.4 kg.

As the final conditioned mass should be 27.2 kg, more water must be added.

Mass of water still needed
= 27.2 kg − 26.4 kg
= 0.8 kg (equivalent to 0.8 L of water)

Repeat the procedure with only 0.8 L of water in the pan.

After two days, all the water has evaporated and the silica gel weighs 27.1 kg. As this is within 1% of the required mass, no more water needs to be added.

Adding Moisture by in situ *Method*

The gel is spread out in a tray (or trays) underneath the false bottom in the display case, and the case is resealed. Assume that after four weeks the RH has gradually dropped to 41% (the RH in the museum during this time is well below 20%).

An *in situ* reconditioning method is chosen. The EMC of gel at 41% RH is 20% (from figure 5). Calculate the amount of water lost as follows:

Mass of water lost
= (original EMC − new EMC) × dry mass (kg)
= (0.23 − 0.20) × 22.1
= 0.66 kg (equivalent to 0.66 L of water)

Place this amount of water in a smaller container situated in the middle of the silica gel tray (under the false bottom). Open three 1 cm holes. After four days the RH goes up to 43%. Open two more holes and the RH increases to about 49% after a further three days.

Removing Moisture by in situ *Method*

In the same museum, during a rather humid summer, the RH has risen to 58%. It is now necessary to remove water by adding dry silica gel. This is illustrated in the following example.

Use the same equation (as for adding moisture) to calculate the water gained. Note that the original and the new EMC are interchanged. Knowing that the EMC of gel at 58% is 25%, one can calculate as follows:

Mass of water gained

$$= (\text{new EMC} - \text{original EMC}) \times \text{dry mass (kg)}$$
$$= (0.25 - 0.23) \times 22.1$$
$$= 0.44 \text{ kg}$$

Calculate the mass of dry gel which must be added to absorb this extra water, as follows:

Mass of dry gel

$$= \frac{\text{mass of water gained (kg)}}{\text{original EMC}}$$
$$= \frac{0.44}{0.23}$$
$$= 1.9 \text{ kg}$$

Place this quantity of dry gel in a small container situated in the middle of the silica gel tray (under the false bottom). Again, open sufficient holes until the RH inside the case drops slowly to near 50%.

In the last two examples of *in situ* reconditioning, it is essential to monitor inside the case to determine whether the RH is changing too rapidly or too much.