Use of the Lascaux Humidification Chamber HC-5 and Lascaux Low-Pressure Table

Organic and cellulosic materials generally account for 90% of the total weight of a graphic artwork. These materials are dimensionally unstable and are subject to constant microdimensional change due to climatic variations. Internal stresses can have a considerable impact, and dimensional changes in the order of 1/40th are not uncommon. This can eventually distort the work or, worse still, lead to creasing and deformations. It is therefore only a matter of time before the first serious signs of ageing appear, such as a loss of mechanical strength or tears along the edges of the paper.
The usual answer to this type of damage is to line the work, often with materials similar to those of the original. Unfortunately, this involves the use of even more unstable materials (animal glues, protein-based water glues, etc.) which become difficult to remove as they age and are particularly vulnerable to microorganism attack. The inevitable degradation of these materials makes relining necessary, with the result that many drawings have been lined more than once. Conservators today are often faced with structural damage, creasing and thinning of the paper due directly or indirectly to earlier linings.
Water is one of the most common factors in the degradation of works of graphic art; and, paradoxically, water is also without a doubt the most widespread substance used in restoration work. Humidifying a work is a delicate and indispensable part of the process of installing or removing a lining and of cleaning or flattening an artwork. As a rule, we use a vaporizer, hot or cold steam generators and GORE-TEX® for the humidifying stage. Because of their highly hygroscopic nature, paper and parchment react very quickly to this form of treatment, and the restorer must be able to control its effects perfectly so as not to accentuate certain deformations or weaknesses (the presence of a water-sensitive medium often brings further problems). Water can be as disastrous in its effects as it can be beneficial, which is why control of this element is crucial. The humidification chamber and the suction table presented here are two equipments which together meet the desired requirements.

The Lascaux Humidification Chamber HC-5

The Lascaux humidification chamber HC-5 is an equipment for relaxing the fibrous tissue of a paper work. It also allows to soften adhesives safely and in a much gentler fashion than any other method, by creating a controllable moist environment. The work is permanently visible through the window, and at the end of the treatment seems to have been remarkably unaffected by the process because it has only absorbed the amount of water that is necessary to relax it. This low level of water input enables the conservator to work on objects which would not withstand other humidification methods. Moreover papers which have been humidified using this chamber are less prone to distortion than those humidified by other conventional methods. The long humidification process (up to 24 hours) ensures perfect penetration of the paper fibres[1] by the moisture. In this way, the paper retains a certain amount of mechanical strength, thereby avoiding the risk of tearing during handling.

Hydrophilic and hydrophobic properties of paper

Water is a very active solvent of paper for both chemical and physical reasons, because it is very hydrophilic and porous. The internal structure of paper consists of layers of cellulose forming a capillary network of variable density depending on the manufacturing method employed:
Paper is a heterogeneous material because the cellulose fibres are not all of the same size or thickness and contain crystalline and amorphous zones.[2]
Highly refined fibres are more hydrophilic but also more supple, yielding a more compact paper. If the fibres are refined further, the largest ones may flocculate, i.e. clump together to give the paper an irregular texture.
A highly calendered paper will be more compact and therefore less porous than a non-calendered one (this is one of the basic differences between tracing paper and watercolour paper). Size, by fixing to the cellulose, makes the paper hydrophobic, thereby preventing the colours in water-based graphic media from spreading.

Water-to-paper bonding levels

When a drop of water is deposited on the surface of a dry paper, it spreads laterally and vertically through the paper by capillarity, forming a multitude of hydrogen bonds with the cellulose. According to James Cazey,[2] water is so bonded to cellulose that a paper which has been dried at 100° C (212° F) will still contain between 0.5 and 1% water. Water is at the origin of the inter- and intra-molecular bonds within the cellulose which give it its stability and also enable the polymer chain to form microfibrils, then fibrils and fibres, before resulting in the fibrous tissue of the paper. Depending on the quality of the fibres, a paper may contain between 15 and 30% water in a saturated atmosphere. Water is retained in the paper by various means, and is called colloidal water, capillary water or excess water, according to the bonding level:
Colloidal water (approx. 3-4% water content of the

[1] Refining consists of a system of knives in a water suspension and has the purpose of fibrillating the fibres. Fibrillation loosens the threadlike elements known as fibrils that make up the structure of the fibres by relaxing the weakest internal bonds.
[2] See Bibliography.

paper) is strongly connected with the cellulose molecules by hydrogen bonds and is almost never affected by conservation treatments. The physicochemical properties of colloidal water vary somewhat from those of "free" water. Colloidal water has an abnormally high density, a different freezing point, does not act like a solvent, is virtually insensitive to water treatments, and does not have the same vapour pressure.
Capillary water is held in the capillaries by hydrogen bonds. The percentage of capillary water depends on the relative humidity and corresponds to the point of equilibrium between the paper and the environment. It varies continuously because exchanges between the paper and the atmosphere are taking place all the time. When flattening paper, what interests us is the capillary water, as this gives the paper its suppleness.
Excess water appears in the paper from the "critical humidity point" onward and corresponds to the fibre saturation point. This level of humidification is achieved when a paper is impregnated with water by immersing it in a water bath or by atomizing a large amount of water onto it. This makes the paper transparent by modifying its refractive index. As it penetrates the paper, the water first hydrates the amorphous regions of the cellulose, which are more reactive, more fragile and more easily reached; the polymer chains spread out, thereby facilitating the hydration of the other regions. This hydration is expressed by a swelling of the fibres and dimensional variations in the paper sheet.

Description of the Lascaux humidification chamber HC-5

Dimensions: 158 x 108 x 55 cm. Aluminium casing, stove-enamelled.
The chamber has a glass front door, giving access to the nylon grid form, and is equipped with ceiling illumination. The artworks to be treated are placed on the nylon grid and are separated by blotters to prevent the vapour from condensing in contact with the grid and to direct it towards the work. The regular flow of cool mist is produced by an external ultrasonic humidifier connected to the chamber by a flexible hose. The cool mist circulates round the papers undergoing the treatment, slowly swells the layers of glue and gently relaxes the paper. A hygrostat provides perfect control of the ambient humidity.
A fan inside the unit increases the kinetic energy of the water molecules, reduces the condensation phenomenon, and encourages the even distribution of the vapour around the objects. To guarantee the climatic stability of the chamber, the fan motor should be set at a slow speed. Setting the fan speed too high could lower the temperature, leading to condensation on the ceiling of the chamber. To prevent this happening, the ceiling is equipped with a heating system which can be set for a minimum temperature to keep the surface of the objects from drying out. If the temperature is too high, the relative humidity is reduced and it is no longer possible to humidify a paper enough to ensure the success of the required treatment. It is also advisable to keep the light turned off while treatment is in progress so as not to raise the temperature inside the unit.
Hydration generally involves some degree of expansion. As the component parts of a work do not all have the same hydrophilic character, attempting to rush the humidification process can have disastrous consequences. The hygrostat makes it possible to program a very slow and progressive rate of humidification based on the slowest hydration speed of the various elements involved (support, adhesives, binders, pigments, etc.). The hygrostat is therefore a safety guarantee for the conservator because it allows the user to select a certain level of humidity and maintain it indefinitely. To avoid water condensing it is advisable to increase the humidity in the chamber slowly and evenly (though the air-circulation rate can also be raised slightly).

Verification and fine adjustment

100% relative humidity can be achieved in about 12 minutes. Good moisture distribution, thanks to the air-flow, has been tested with filter paper impregnated with cobaltous chloride salts. Papers treated in this way are blue when dry and turn pink as the relative humidity rises. The tests indicate a uniform increase in humidity right across the chamber.

Humidifying a paper

The vapour generated by the ultrasound humidifier migrates into the paper, where it is adsorbed onto the walls of pores and forms a monomolecular layer before condensing in the narrow sections and filling the capillaries. Liquid water fills the largest pores first. But here the opposite happens (the vapour first condenses in the finest capillaries), and the volume of water delivered by this type of humidification is much smaller than by conventional methods. There is no excess water, because the paper finds a state of equilibrium with a relative humidity close to saturation. Relaxation takes place and the paper becomes more supple and dimensional variations are less than those induced by humidification using the conventional methods.
With more traditional humidification, the paper reaches its critical humidity point and contains excess water.
Drying a paper saturated with water in the open air can be divided into three phases:
The excess water evaporates off the surface of the paper. This stage goes quickly and can be further speeded up according to the humidity, temperature and circulation speed of the ambient air. Characteristic of this stage are the gloss and relative transparency of the paper.
From the critical humidity point onwards, the rate of evaporation falls. The water evaporates from the inside of the paper and no longer from its surface. The molecules therefore have to expend more energy to escape from the liquid because the fibrous tissue closes up and the capillary pressure increases. The evaporation rate at this stage depends not only on external conditions but also on the degree of hydrophilia of the paper. It is at this stage that the paper has a tendency to cockle because it is not drying evenly and the fibres have to

reorganize themselves under a range of stresses induced by the drying.
Evaporation virtually ceases as equilibrium sets in between the paper and the relative humidity.
Humidification in the humidification chamber introduces no excess water and is much more uniform and less abrupt. The first drying stage as described above, therefore does not exist for papers humidified by this method. The paper will also show less tendency to deform during drying, especially if the process is retarded and takes place in a controlled atmosphere.
If the conservator wants the paper to absorb a large quantity of water, it is not enough to provide a high relative humidity. The saturation level of the unit must also be raised and this is temperature-related. If the room containing the humidification chamber is too cold, the maximum amount of water vapour the chamber can contain may be insufficient to ensure a good level of humidification and some of the vapour may condense if the output rate of the ultrasonic device is too high. The optimal ambient working temperature for the humidification chamber is therefore between 17 and 22° C (63-72° F).
Although the air circulation inside the humidification chamber is very regular, it may sometimes happen that the upper surface of the work is more moist, particularly if the work is on blotters. This difference in humidification can be an advantage to the conservator. The object may be placed face-up or face-down on the blotter, depending on the nature of the work and the conservation problems involved. Particularly fragile surfaces (e.g. gouaches containing colours which may bleed) can be protected by securing the edges of the work, face-down, onto a blotter. This avoids any direct contact between the paint layer and the moisture.

Removal of lining after humidification
Removing the lining from the work should be commenced once the glue is completely soft. The support lining can be separated from the original by slipping a scalpel or Teflon spatula between the support and the work, if possible face-up to avoid damaging the surface (this applies particularly to pastels, charcoal, etc.). Removal should be completed in one go, without interruption, so that the old glue does not have the time to dry.
It is often possible to preserve a removed support lining, because the lining retains sufficient strength despite the high degree of humidity needed to soften old adhesives. However, it is important to make sure that the expansion capacity of the support lining is not greater than that of the original support otherwise it could tear, particularly if it is only glued along the edges of the support. In such cases, the support lining should be thinned down mechanically prior to humidification.
Although, as a rule, all water-soluble adhesives can be softened in the humidification chamber, some glues can prove particularly stubborn. In such cases it may help to apply the heating system during the final hours of humidification or use in a hot-vapour (steamy type) during the removal ot the lining.

Cleaning foxing
Cleaning foxmarks in pastel drawings can present a whole range of problems. The first step is to humidify the work for about 6-8 hours before treating it on the low-pressure table. Once the fibres are swollen, the drawing is placed face-up on the low-pressure suction table and aspirated gently for a few minutes. The marks now migrate from the moist work into the underlying blotters. The still-moist work must then be returned to the humidification chamber (the blotters having been changed in the meantime). This process is repeated as often as necessary. It is important never to let the work dry out completely, as this would jeopardize the cleaning process. If the treatment is interrupted too soon, the foxing risks rooting itself firmer in the paper and will be harder to remove later.

Changes in colour
The colours in traditional watermedia contain binders like gum arabic, egg albumen, gelatin, egg yolk etc., as well as plasticizers such as honey which are prone to dehydration as they age. This can make the colours duller and matter. In some cases, treatment in the humidification chamber can regenerate these binders or plasticizers, resulting in richer, more brilliant colours[3]. It is impossible to say how long such regenerations will last; the colours will certainly fade again sooner or later, depending on the conservation conditions of the work.

Advantages of the humidification chamber HC-5 in brief

1. Humidity can be exactly controlled.
2. The humidity acts uniformly on the paper. It does not wet the surface of the work but penetrates deeply and evenly into the paper fibres, thereby avoiding stresses and deformations.
3. Uneven stresses and deformations in the paper can be treated during humidification.
4. Treatment can be interrupted at any time if the integrity of the work is threatened (by colour migration, etc.).
5. Delicate objects (pastels and other media with low binder content) can be kept facing up during the treatment without the surface being in contact with anything. This is also a great advantage in the case of paint layers containing a high percentage of binder.
6. The work can be observed through the glass front door while treatment is in progress.
7. Lining removal (separating a work from an auxiliary support) is one of the most important operations which can be carried safely with the help of the humidification chamber HC-5.

[3] See M.K. Weidner 1993; A.F. Maheux and W. McWilliams 1995.

The Lascaux Low-Pressure Table

Stain removal

When a work presents soluble stains, they can be dissolved by washing them out in a water bath or by intervening on a "spot" basis. These treatments are always applied and adapted on a case-to-case basis, according to the state of the work and the medium. Although spot treatments may seem less drastic at first sight, it should not be forgotten that a drop of water placed in the centre of a stain can form a ring or halo by diffusing the dissolved material towards the outer edges of the wetted zone. The suction table is a precious asset in minimizing this risk.

Stains consist of substances of various degrees of solubility which clog the pores in the paper. A suitable solvent applied to the surface of the paper spreads by capillary action and dissolves the products making up the stain. The solvent migrates in all directions, advancing from the moist parts of the paper to the dry parts. It is very soon brought to a halt in the vertical axis, which is much smaller than the lateral dimensions. The horizontal stratification of the fibres in the paper also encourages this lateral diffusion. The more solvent that is added, the more it will dissolve the stain but will also migrate beyond the stained zone. The drop of solvent will dry first at its edge, because it is in this region that the interface with the air is greatest, and the dissolved products will stay where the liquid has carried them, creating a halo effect. The choice of solvent is therefore not just a matter of its stain-dissolving properties but also of its ability to penetrate the paper in order to drain the dissolved products and then to evaporate quickly so as not to leave a halo.

Action of the suction table on the circulation of a liquid in the paper

A work placed on a suction table is between two environments with different pressures as the vacuum pump creates an area of low pressure in the table tank. The air moves from regions of high pressure (atmospheric pressure) towards low-pressure zones (vacuum pump). If "spot" water treatment is performed on a work, the outside air pressure will therefore drive the liquid across the work towards the vacuum pump. Thanks to the suction table and an adequate power level, air flow will limit the lateral diffusion of the liquid and enable it to penetrate the smallest capillaries. The risk of leaving a halo behind is greatly reduced because the substances to be eliminated are carried towards the suction table (provided that the speed at which the solvent is deposited is not excessive).

Capillarity phenomena in the paper

The propensity of a liquid to penetrate the fibrous tissues of paper depends on its surface tension, the atmospheric pressure and the diameter of the capillaries in the paper. The wettability of a paper can vary enormously depending on whether the size is hydrophilic or hydrophobic, but the greater the surface tension of a fluid the more it will tend to form a droplet and the harder it will become for it to wet a solid. The reduction in the surface tension facilitates wetting but, in accordance with Jurin's Law[4], this inhibits capillary expansion. A flow of air or liquid traverses a porous material preferably by the largest pores; so, according to Stefan Michalski, in paper 90% of this flow would pass through only 1% of the pores. Thus a great many of the capillaries in paper are almost inaccessible to solvents. But, as we have seen, water causes the fibres to swell up by hydrating the amorphous regions and forces the chains apart, thereby making the inaccessible zones accessible to hydration after all. This process is not instantaneous and as the fibres swell, the capillaries narrow, thereby impeding the circulation of the water and powerfully compressing the air in the smallest capillaries. Thanks to the low-pressure table, the liquid spreads into the largest pores but is also driven into the finest capillaries if the depression force is greater than the capillary pressure. The depression force exerted by a vacuum pump is 30 Hg.[5] As a rule, the depression required is between 7.5 and 25 Hg, according to the porosity of the paper. Timothy Vitale provides a method of measuring the porosity of paper and a series of charts for adjusting the strength of the depression according to the porosity of the paper and the surface tension of the solvent used. The greater the porosity, the less the pressure reduction that will be needed and the shorter the treatment time.

The blotters or filter papers which are inserted between the work and the suction table play a very important role. Their purpose is not just to prevent the pattern on the stainless-steel plate from marking the work; above all they play a part in the capillarity phenomena by also "soaking up" the liquids and disintegreated materials (they must of course be replaced regularly as they become saturated). The blotters act as a porous material to recover the solvents or water, which is then transferred to the suction table by evaporation. Evaporation is faster, the lower the pressure (under 1 atmosphere) in the tank. It is advisable to protect the motor from humidity by installing a siphon system between the table and the pump where the vapour can condense.

Evaporation of water

The liquid state is a disordered, contracted state of matter. The gaseous state is also disordered, but is not contracted. It is directly affected by temperature and pressure: a gas expands when its temperature is raised, and contracts when it is compressed. This means that, for the same amount of matter, the gaseous state possesses more energy than the liquid state (kinetic energy and potential energy associated with the work necessary to separate the molecules). A liquid can be characterized by its boiling point at a given pressure. For example at normal atmospheric pressure (1 atm) water

---

[4] Jurin's Law: "The height to which a liquid rises in a capillary varies in inverse ratio to the radius of the tube at the point where the liquid stops, and in direct proportion to the surface tension."

[5] 30 Hg = 1 atmosphere = 1013 mbars = 1.033 kg/cm^2.

boils and evaporates at a constant temperature of 100°C, but at lower pressures the boiling temperature is also lower.
The boiling point marks the transition from the liquid to the gaseous state by evaporation, but evaporation also takes place at temperatures below boiling because, if there is a free space beyond the surface of the liquid, it is always occupied by a certain amount of the relevant gas. Molecules with sufficient kinetic energy can escape from the surface of the liquid through evaporation. A liquid can be defined by its saturation vapour pressure, because liquids are more or less volatile. The evaporation rate of a liquid therefore depends on several factors:
the saturation vapour pressure of the liquid the temperature which can limit the cooling of the liquid during evaporation and therefore maintain the kinetic energy of the molecules at a constant average value the pressure the surface of the liquid, because the larger the surface, the greater the number of molecules likely to escape at any one time air movement, which prevents vapour from accumulating in the vicinity of the liquid and accelerates its dilution in the atmosphere because molecules cannot return into the liquid.
Depending on the size of the suction table, there are two suction modes: vertical or lateral. For large tables, it is better if suction takes place laterally at the edge of the table. This ensures better suction distribution and creates a flat movement of air which speeds up evaporation and facilitates the drying of the paper.

Replacing the aluminium plate by a porous polyethylene plate

The performance of this suction table can be significantly enhanced by replacing the perforated aluminium plate by a porous polyethylene plate. The latter has a much smoother surface because the pores are 250 µm in size compared with 1 mm for the holes in the aluminium plate. As we have already seen, evaporation speed depends on the surface of the liquid. This "evaporation surface", like the amount of liquid it can absorb, is substantially greater with the polyethelene plate than with the metal plate. When leaf-casting, the suction exerted by the polyethylene plate alone (with the vacuum pump off) is therefore efficient enough to reduce the vacuum pump start-up time to about ten seconds. Cutting the pump start-up time is very important in limiting the risk of polluting microparticles in the atmosphere adhering to the surface of the work (note: if you want to leave a drawing to dry on the worktable with the table switched on, it is a good idea to cover the work with GORE-TEX® to filter out these particles).

Converting the suction table into a "lining removal table"

As Marilyn Kemp Weidner[6] has shown, the suction table can be of great help in lining works of art; but it can likewise serve as a "lining removal table" thanks to the polyethylene plate. We have seen that it is often necessary to humidify a work when detaching a lining in order to soften the old glue to separate the work from the lining paper. After moistening the work in the humidification chamber, the work is placed on the suction table,[7] with the tank already connected up to an ultrasonic humidifier instead of the vacuum pump. This provides the conservator with a rigid, smooth, vapour-diffusing worktop which keeps the work moist during the operation. The vapour can be focused on the work with a Hostaphan film.

[6] M.K. Weidner 1985.

Olivier Masson
Conservator of works of art on paper
Zeltweg 40, CH-8032 Zurich

Valérie Luquet
Conservator of works of art on paper
12 place de la Libération, F-86310 Saint-Savin

Literature

Caldaro, N. "Tests on the effects of the use of ultrasound in the humidification of paper", The Book and Paper Group Annual, A.I.C.-B.P.G., 1992, pp. 1-20.
Cazey, J. Pulp and Paper, New York, Interscience publishers, 2nd edition, 1960.
Boissonas, P.B., and Percival-Prescott, W. "Some alternatives to lining", Preprints of the ICOM conference, Copenhagen, 1984.
Bartelt, E. "Praktische Erfahrungen bei der Restaurierung von Miniaturen", Maltechnik-Restauro, No. 2, 1980.
Futernick, R. "Leaf casting on suction table", Journal of the American Institute for Conservation, Vol. 22, No. 2, 1983, pp. 82-91.
Keyes, K. "Japanese print conservation, an overview", IIC Conference, Kyoto, 1988.
Keyes, K. "Some practical methods for the treatment with moisture of moisture-sensitive works on paper", ext. from Conservation of historic and artistic work on paper, conference in Ottawa, 1988, pp. 99-107.
Luquet, V. "Restauration du parchemin: comblage de lacunes avec du parchemin reconstitué", graduation thesis, Paris, ENP-IFROA, 1998 (can be consulted at the IFROA library and in part on the Internet: www.ifrance.com/2PG/extraitme.htm).
Maheux, A. F., MacWilliams, W. "The use of the ultrasonic mister for the consolidation of a flaking gouache painting on paper", The Book and Paper Group Annual, A.I.C.-B.P.G., Vol. 14, 1995.
Masson, O., Percival-Prescott, W. "The use of the Lascaux humidification chamber HC-5 in the treatment of works on paper", Paper Conservation News, No. 43, 1987, pp. 4-7.
Masson, O., Percival-Prescott, W. "L'Utilisation de la chambre d'humidification HC-5 pour le traitement d'oeuvres sur papier", extr. from Traitement des sup ports, travaux interdisciplinaires, Conservation-

[7] With the work placed face-down on the table, it is good practice to cover it with a thick nonwoven overlay or GORE-TEX® to protect it from scratching and abrasion.

restauration des biens culturels, Journées d'études de l'A.R.A.A.F.U., Paris, 1989, pp. 207-212.
Michalski, S. "Suction table, history and behaviour", extr. from Preprints of the 9th annual meeting of the A.I.C., Washington, 1981, pp. 129-136.
Michalski, S. "The table: a physical model", extr. from Preprints of the 12th annual meeting of the A.I.C., Los Angeles, 1984, pp. 102-111.
Monier, V. Etude sur le séchage des papiers anciens, graduation thesis, Paris, I.F.R.O.A., 1992. (can be consulted at the I.F.R.O.A. library)
Perkinson, R. "Design and construction of a suction table", Journal of the American Institute for Conservation, Vol. 20, No.1-2, fall 1980/spring 1981, pp. 36-40.
Purinton, N., Filter, S. " GORE-TEX®: an introduction to the material and treatments", The Book and Paper Group Annual of the A.I.C., Vol. 11, 1992, pp. 141-155.
Vitale, T. "Observations on the theory, use, and fabrication of the fritted glass bead, small suction disk device", The Paper Conservator, Vol. 12, 1988, pp. 47-67.
Vitale, T. "Effects of water on the mechanical properties of paper and their relationship to the treatment of paper", extr. from Materials issues in art and archeology III, Materials research society symposium proceedings, Vol. 267, Pittsburgh, 1992, pp. 397-428.
Weidner, M. K. "A vacuum table of use in conservation", Bulletin of the American Institute for Conservation, Vol. 20, No. 1-2, 1974, pp. 115-122.
Weidner, M. K. "The suction table: a ten year review of its development", extr. from Preprints of the 12th annual meeting of the A.I.C., Los Angeles, 1984, pp. 94-101.
Weidner, M. K. "Water treatments and their uses within a moisture chamber on the suction table", extr. from Preprints of the 13th annual meeting of the American Institute for Conservation of Historic and Artistic Works, Los Angeles, 1985, pp. 127-139.
Weidner, M. K., Zachary, S. "The system: moisture chamber/suction table/ultrasonic humidifier/air filter", extr. de Congrès de l'American Institute for Conservation, 1988, pp. 109-115.
Weidner, M. K. "Treatment of water sensitive and friable media using suction and ultrasonic mist", The Book and Paper Group Annual, A.I.C.-B.P.G., Vol. 12, 1993, pp. 75-84