



The mechanisms of leather drying

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The management of physical properties such as flexibility, looseness, texture, area and strength has been a focus of leather manufacture for over a century. Papers and book chapters covering the quality and conditions during drying have appeared on a regular basis over that period.

The drying of vegetable tanned heavy leathers has always required very close control and can be especially problematical when compared to the drying of generally thinner leathers based on chromium tannages. However, the advent of chromium free leathers has brought new challenges due to the complexity of balancing drying conditions to ensure tight, evenly dried material.

At the same time new equipment has been developed to support rationalisation and machine linkages, which in turn has provided new options and opportunities.

1. THE REMOVAL OF WATER FROM LEATHER

Any decision about what drying method is necessary for a particular leather starts with an understanding about the mechanism of drying. All drying involves the shift of water as a liquid to a gaseous state, also known as vapour.

For leathermaking the emphasis is on this vaporisation. A serious academic question revolves around: "When does the drying process start?"

One conclusion is that drying begins the moment that leather is removed from wet processing and starts to lose water, and that includes operations such as horsing up and draining. The setting/samming operations are also needed to prepare the leather for drying by removing excess water and to create a flat and manageable piece. This may not serve as the prime focus of vaporisation, but these operations are an important part of the overall drying operations to suit the specific needs of the overall drying method for the tanner.

Vaporisation

Water molecules are bound together through weak bonds that when broken can allow water to vaporise into the atmosphere as a gas. As the gaseous water content of the atmosphere increases, the atmosphere becomes more humid towards a relative point at which the atmosphere is said to be saturated.

This point is called 100% relative humidity (RH) and depends on the atmospheric pressure and temperature of the air. The colder the air the less water it can carry. Air with no water content has a 0% RH, and absolute humidity is the physical measurement of the water content of the air and is usually given as grams of water per grams of air. It is important to remember that the absolute humidity of air at 100% RH changes as the air gets hotter. In a closed system the RH of the air results in an equilibrium system where the water moves from the leather to the air (and back) on a continuous basis and this occurs even in the final leather article.

Vaporisation occurs using two main methods in leather making:

Evaporation: This occurs from the edges of a bulk of water, e.g., the surface of a pond, and the atmospheric pressure stops the water molecules (inside the bulk water) from vaporising. Evaporation is the reason for leather drying when hung, toggled or tacked.

Boiling: This is a special case of vaporisation, being the vaporisation of water inside the bulk of the water. When water boils in a container this can be seen as bubbles developing from the middle of the liquid. Boiling is limited by two environmental conditions:

- 1] At sea-level the atmospheric pressure is generally high (subject to weather conditions) and water boils at 100°C.
- 2] At low atmospheric pressure water can boil at very low temperatures. For example, on the top of Mt. Everest, water boils at 71°C; or in a partial vacuum, water might boil at, say, 25°C.

So temperature and pressure govern whether water can boil, and boiling always results in very rapid vaporisation of water.

During evaporation the water leaves the evaporative front of the leather. This could be either from the surface of the leather or from deeper inside the leather as the drying proceeds into the structure. The leather dries from the surface of the leather, that is from the outside, with relatively slow water migration from the inside towards the surface. Also, the edges of the piece of leather are normally the first to dry as they have an extra drying face and hence increased surface area.

During boiling the water, as vapour, emerges from deep inside the structure and rapidly travels outwards. Loose chemicals can be pushed (or migrate) by the gas vapour as it moves to the outside, particularly when there is interfibrillary water.

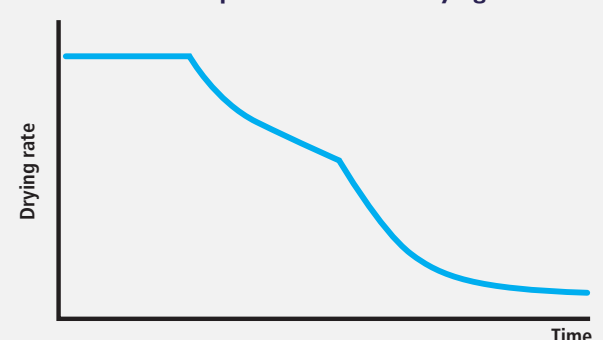
As drying commences, the initial rate is constant, and then becomes variable. A representation of the change in drying rate that proceeds in wet leather from the start time onwards is shown in *Panel 1*.

Cooling effects also occur, and this evaporative cooling is associated with all liquid to gas changes. This results in the drying surface lowering in temperature. As the bonds in liquid water require heat to break they take heat from the leather to do this. This causes a cooling of the leather, and this then needs to receive heat back from the air if the evaporation process is to continue.

The three phases of drying

Drying of leather occurs in multiple stages, and are separated by where the drying is taking place and how the drying rate changes.

Panel 1: The three phases of leather drying.





1ST - PHASE DRYING

This is described as surface drying where the vaporisation is rate-limited by several key conditions:

- The relative humidity of the air,
- The speed of the air (and its volume),
- The temperature of the water in the leather,
- The replacement of surface water.

This last condition is not often mentioned in drying literature and is overlooked by tanners, particularly by vegetable tanners of heavy leathers. In particular, a heavy tannage or retannage that results in small spaces between leather fibres slows the replacement of water on the surface and the 1st-phase drying will be slower.

2ND - PHASE DRYING

This moves the evaporative front to inside the leather and the drying rate falls (and continues to do so) as the front moves into the leather. The drop off in the drying rate as the front moves inside the leather is shown in *Panel 1*. Here, evaporative drying during the second phase is taking place from the water interface in the capillaries between fibre bundles.

3RD - PHASE DRYING

There is a further locational change where the drying front has moved to the fibre bundle surface or at hierarchies lower than fibre bundle level. The spaces between fibres are smaller, water vapour diffusion slower, and exchange of gas to these spaces occurs at the molecular level. In this event any unbound water undergoes sorption or desorption—in a manner similar to leather conditioning. Over-drying results in the removal of all unbound water, and would not include a loss of bound water as often believed.

Low pressure drying

Low pressure drying, such as vacuum drying, results in a leather drying where the 1st-phase does not take place, but is dominated by the 2nd-phase limitations.

This drying by low temperature boiling is the simultaneous vaporisation of water molecules anywhere in the leather. This can be compared to evaporative drying as found in other drying methods commonly used where the molecule change can only occur at the evaporative front.

It may also be possible that, whilst low pressure drying is dominated by 2nd-phase mechanics, it may be that 3rd-phase drying will be taking place. Here, very little research has been done to understand how much drying at fibre level is taking place, if it is useful in leather properties, or even if it is counter-productive in terms of leather properties. Trial attempts to remove bound water have proven extremely difficult and only seem to occur at temperatures just before collagen degradation.

2. MANAGING THE DRYING OPERATION

It is clearly understood that the chemistry of the leather is important, and careful gains made within wet processing can easily be overridden by a poorly controlled drying system. Chemistries that seem to have failed having resulted in poor leathers may just be the victim of misunderstood drying conditions.

The events involved in different stages of drying, have already been discussed. These need further consideration as they are critical in the context of what particular aesthetic properties the tanner needs to develop in a range of leathers.

Suspension drying

The simplest form of drying is where leathers are dried suspended without tension, normally over horizontally mounted poles. The leather dries and the water moves from between the fibres resulting in closer proximity of the collagen fibres. This results in increased cohesion between the fibres.

The lack of tension in the method results in an area loss, the plumping up of the fibres and a higher angle of weave. The lack of tension will also result in increased plasticity of the leather. The hang drying method gives the highest degree of texture or softness in the leather surface.

Toggle drying

Leather is clipped using spring-loaded toggle clips onto both sides of a perforated metal frame and enables the leather to be tensioned. This way, varying degrees of set are achieved by pulling the clips to the correct level and then clipping them into the perforations. Toggles can be aligned as opposites, but a triangular alignment can help prevent folds. After fixing the leather to the toggle frames, the frames can often be split and expanded (symmetrically or asymmetrically) to increase tension within the leather. This also results in increased area yield, a lower angle of weave and a firmer leather than provided by suspension drying.

The frames can then be loaded into machine driers or can be positioned in drying rooms that allow for the simultaneous injection of drier air and the extraction of humidified air. The humidity of the atmosphere will increase as the water vaporises out of the leather.

Vacuum drying

Leather is placed grain side down onto a heated vacuum table which may be smooth or textured. For low gloss levels, textured vacuum tables are recommended. The leather is then slicked out following the underlying fibre structure to gain the highest area. The vacuum hood is then lowered onto the table surface and a partial vacuum is drawn. The extent of the vacuum and the temperature of the table will allow the vaporisation of the water by boiling. This vaporisation is rapid and the gaseous water will exit the leather. The vacuum hood has to be then evacuated to ensure low atmospheric pressure. The drying time of the leathers can be just a few minutes to get the leather moisture down to below 30%. Vacuum drying will give the leather a very low degree of surface texture.

Through-feed drying/conditioning⁽¹⁾

This form of drying is a low temperature operation coupled with very precise control of the RH. The leather feeds into a drying cabinet on a horizontal conveyor, where it is held securely within pairs of strings that maintain the leather in an extended state as it passes through the unit. The air is delivered via a heat pump arrangement at high velocity to both the grain and flesh parts within a closed loop system. This creates a very fast removal of water to a moisture content that is in equilibrium with the RH. This way a leather can be dried within a time period as short as 40 minutes to a precise moisture content suitable for vibration staking. The labour component in this arrangement is very low as the system readily enables machine linkages both before and after drying.

Wet-stretching / wet-staking operations⁽²⁾

This is an important machine addition within drying operations. In appearance the machine is similar to a conventional through-feed vibration staking machine. Leather



after samm/setting is offered to the machine, often directly by conveyor, where it is subjected to mechanical stress by a series of oscillating pins. The pin configurations are different to the conventional through-feed vibrating staking machine, and the effect is to extend the leather, but also to cause fibre separation within the wet structure. This extension is retained when rapidly followed by drying – normally by direct machine linkages – but the fibre separation or loosening of the structure also causes a faster release of water from within the structure.

Although it is predominantly used before the initial drying operation, the operation can be employed directly after vacuum drying and before tension free drying, but also when the leather is half dried when using the through-feed drying/conditioning operation.

Combinations of drying methods

Combinations of drying methods exist as described, and they allow a tanner to get the benefit of several of the methods. For example, it is normal for a tannery to start with vacuum drying and then finish the process by suspension drying. A tanner thus gets the speed of vacuum drying, but the texture of hang drying. And uses are growing within other combinations as offered by wet stretching/staking and through-feed condition drying, especially as these operations lend themselves to the linking of various machines together.

Paste drying

Very few paste drying units are now used, and their uses are limited mainly for speciality leathers and drying splits. Nevertheless, it is a serious technology.

In this operation, a sticky paste (starch or cellulose based) is sprayed onto a glass or metal plate, with the leather then slicked flat grain to the adhesive loaded plate to ensure adhesion of the leather and a lack of folds. The leather is then placed into a drying tunnel to allow the removal of moisture from the flesh side, with the adhesive holding the leather tightly in place and preventing any area shrinkage.

The leather is constantly heated by the air in circulation at controlled temperature and RH. After drying the leather is taken off the plates and the grain/adhesive buffed off. This operation

was originally designed for corrected grain leathers and splits where there is a low degree of surface texture. It is possible to wash the grain in certain situations.

The general properties of different drying methods

In conjunction with previous chemical processing and machine operations, many different leather characteristics can be developed in the drying operations. These are given in *Panel 2*. The parameters used during the different drying operations are central to success but in general:

- The slower the drying the better the aesthetic properties of the resulting leathers, although today's environment requires a very high throughput and tends to favour a rapid drying method.
- The amount of tension during drying significantly influences the physical properties including softness, the elasticity/plasticity, strength, grain texture and area.

The requirements of different tannages

The type of tannage and the thickness of the leather are also two very important criteria that have to be taken into account for a successful outcome. For example:

Heavy vegetable tanned leathers: These need to be dried tension free or toggle dried very slowly and at a low temperature (35-45°C). It is not unusual to start with quite a high RH to ensure that too rapid drying out of the surface layer does not result in a dry surface (ie. case hardening) and trapped moisture in the underlying layers.

Chromium tanned leathers: Dried originally with plate temperatures as high as 85°C, the plate temperatures have gradually reduced due to machine improvements towards a more general working range of around 45°C or less, coupled with as low an RH as possible. In addition, the leathers should not be over-dried when they get to 14% moisture. If they are vacuum dried, then like all leathers they will benefit from a low table temperature (25°C – vacuum permitting) as lower temperatures result in less energy for cohesions to form, and hence a softer leather.

Panel 2: The general properties of the different drying methods.

Property	Hang	Toggle	Vacuum	Condition dry	Paste
Labour intensity	●	●●●●●	●●●	●	●●●●●
Leather plasticity	●●●●●	●●	●●●	●●●●	●
Grain texture	●●●●●	●●●	●	●●●	●
Capital outlay	●●	●●●●	●●●●●	●●●●●	●●●
Drying rate	●	●●	●●●●●	●●●●●	●●●●
Area gain	●	●●●●●	●●●	●●●●	●●●●●
Drying surface	Both sides	Both sides	One side	Both sides	One side

Key: Low ● Low-medium ●● Medium ●●● Medium-high ●●●● High ●●●●●

Note: All of the rankings are subjective assessments by the author, but serve as a starting point, subject to correction in improved technology.



Chromium-free leathers: Over and above vegetable tanning methods, there are two broad categories for chromium free tannages:

1] *Glutaraldehyde:* The basic tannage needs strong support by retannage to achieve shape retention, texture and high performance in the final leather. The drying is therefore strongly linked to the nature of the retannage that they undergo. The amount of fatliquor is high and also appears to be critical in the drying rate and the final leather properties. This especially concerns the amount of sorption/desorption of water as a result of hydrophilic tan/retanning chemicals used to gain such properties as dimensional stability.

2] *Modified triazines or polycarbamoyl sulfonates:* These products avoid conventional acid/salt pickle systems. As the acid/salt pickles generally increase the angle of weave as a result of minor swelling, pickle-free leathers can therefore have a flatter angle of weave. As leather fibre angle of weave decreases, the strength properties decrease in proportion. These leathers also need high offers of retanning agents and fatliquors so the drying operations become more critical and demand good control. Tight tension during drying results in the weave flattening which weakens the leathers further.

Mechanical softening: After drying, the leather has to be mechanically softened, and this requires an often very specific moisture content for a particular type of leather texture. If this cannot be achieved by drying control, then the leathers need rewetting or conditioning to the correct level of moisture. The final moisture content can thus be achieved in different ways, but the fundamental point is that this is critical and must be brought about. If this is not performed correctly, then major structural damage can occur to the leather. This is most commonly seen as loose grain break.

Summary

The movement of water from leather to the outside atmosphere can be controlled paying careful attention to air flow rates, temperature control and the tanning chemistry, where the evaporation will determine the speed of drying. In addition, the quality of leathers can be affected by the techniques and operations that are used in leather drying, as these are critical in developing the particular aesthetic properties that the tanner needs.

It should also be taken into account that the chemical processing and previous mechanical operations need to be carefully manipulated and match the drying method to the range of properties are required. The chemistry and preparation in the wet processing can be significantly developed in these critical drying areas.

The maximisation of the surface area through careful control, the development of ultra-soft leathers and grain textures, and attainment of the highest standards in physical properties enables tanneries to maximise profits from their starting raw materials. ☺

Acknowledgements

1 & 2: *A Framework for Leather Manufacture by Richard Daniels and Walter Landmann.*

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