A New Drying Application for Garment Leather

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Summary

In the present investigation the effect of two drying alternatives is analyzed on a fine garment leather. Natural hang drying is compared to tumble forced convection drying. The project is of interest due to the extended drying time under a high humidity environment which demands a high inventory of skins and a long overall manufacturing process time. The two drying processes deliver leather pieces of different characteristics, consequently, the physical and subjective properties of the products are compared.

The forced convection drying process is set up for the conditions that best maintain the quality of the leather compared to the natural convection drying process. The results show that tumbler drying causes a greater area contraction with respect to natural hanging drying; however, a more pliable leather is obtained, optimal for a garment leather application with suitable elasticity. Both drying alternatives are acceptable when the physical properties are compared, both passing the standards required for a garment leather application. The humidity is also analyzed at the exit of the tumbler drying equipment to obtain a moisture curve that helps to define the moment at which the leather reaches an appropriate humidity so that the drying process can be stopped.

1. INTRODUCTION

The traditional process of leather clothing manufacture includes a drumming step which is usually performed to provide softness to the leather. Tumbler drying may be carried out at the same time the leather is drummed. This drying step may reduce both the process time and investment in the inventory of drying skins. This alternative may be more suitable during the rainy season because then the drying is even more problematic because of the high ambient humidity. The humid environment causes the drying time to be extended from around twelve hours on a dry day up to several days. The drying process speed-up is important because it is the time limiting step of the leather manufacturing process.

The drying step is important because, at this stage, the tanner may gain or lose money depending on the drying conditions. Area is lost when water is removed from the space between fibrils, occasioning lateral shrinkage of fibres,[1] so that successive molecules in the same row approach each other. This occurs when the average moisture content drops from about ~50% (calculated on a moisture-free basis) to 27%. Mathematical evidence shows that longitudinal shrinkage diminishes actually at ~9% moisture content, when end-to-end contact between molecules is prevented by accumulation of chrome in the region of d-bands of stained fibrils of collagen as seen by electron microscopy.[1] This is one of the mechanisms through which tanning prevents bonding of molecules together and preserves elasticity and flexibility in leather. An SEM study showed that drying causes agglomeration of fibrous collagen units in the central layer of the leather.[2] The lowest degree of agglomeration was observed in a slow drying mode (several days at 20-23°C) whereas the highest agglomeration was observed in fast drying modes (2 hours at 104°C followed by several days at ambient temperature). This agglomeration phenomenon is undesirable since it results in area loss; therefore, most tanneries rely on drying processes that are carried under natural slow conditions. However, forced drying conditions may be used to speed up the drying process while trying to maintain the leather area.

Various technologies and processes have been analyzed and summarized in the literature.[3,4] Specific references have additionally dealt with the problem of area yield reduction while drying by means of both hanging and toggling techniques[5] and with the mechanical properties resulting from the effects of the stretching and the drying rate,[6] and with the application of the heat pump principle with the disadvantage of the implementation cost.[7,8] Furthermore, some other references have dealt with technical issues rather than focusing on the area reduction, such as Liu *et al.,* (2001)[9] that showed data indicating some favourable conditions that produce a stronger and a softer leather, such as a lower drying temperature, a shorter drying time, and a proper initial water content in the leather.

Several air flow and microwave power conditions have been also proven in a microwave-assisted drying of chrome-tanned leather,[10] where it was shown that the air flow, the magnetron power, and the removal of water vapour are important parameters in the drying of

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leather if the manufacturer requires a leather with a soft feel and smoothness, but with more shrinkage than that of leather dried by conventional processes.[11] A significant area increase of 16% can be achieved by using a combined drying process of vacuum plus stretching (toggling), compared to the regular vacuum-dried leather without stretching.[12] Thus, toggle drying produces high area yield, but may result in stiffer leather.[13] There is a direct link between grain break and stiffness of leather, data indicating that stiffer leather often results in poor break. The research showed that residual water content is a key factor for softness, a result that agrees with that of Jeyapalina *et al.*[14] Novel technologies such as radio frequency (RF) heating for leather drying have been compared to conventional air drying;[15] RF heating produced leathers of comparable quality both at laboratory and semi-commercial scale trials. Leather drying by radio frequency heating resulted in time reduction by more than 80%, at favourable energy costs, although the authors do not have any knowledge of the practical use of this technology today. Old references can even be found showing how the drying process has been an issue of interest in the leather manufacture since 1966.[16]

Tumble drying as a new application in leather drying has not been found in the scientific literature, only a few references to cloth drying, as in Pradeep *et al.*[17] They discussed the drying processes of four different designs of household clothes tumble dryers using electric power input and presented the relative advantages and disadvantages and the energy analyses of the dryer designs. In the same year, Pradeep *et al.*[18] compared the traditional electric household dryer with a new design based on a water-to-air finned tube heat exchanger; it was found that the latter design showed shorter drying times (15-18 minutes), lower moisture extraction rates (defined as the total power consumed multiplied by the drying time in hours, divided by the mass of water evaporated from the clothes), for the same power input, and hence significantly more efficient (11%) than the traditional electric equipment. In further research (Pradeep *et al.*)[19] a theoretical and experimental study of a novel water heat exchanger that heats the air in a domestic clothes tumbler dryer in place of a traditional electric heater, with a view to improve its energy efficiency, is presented. Modelling of a waste heat recovery heat exchanger has been undertaken using an EES software package to assess its effect on the drying cycle. The new dryer was found to have shorter drying times, better moisture extraction rates for the same power input and hence more efficient than the traditional dryer. Although there is use of tumbler drying in drying jeans with equipment similar to a tanning drum, scientific information about that process has not been found.

In regard to patent applications, however, plenty of references can be found where different rotary dryer configurations have been proposed. The most recent and relevant to us may be the design where infrared energy is used to dry clothes,[20] and also a fuel cost and drying time optimization for a traditional rotary convection dryer for clothing.[21] These references and the commercial equipment that can be found are proof that tumbler drying is economically feasible. Within this context and faced with the lack of information about tumble drying of clothing leather, the objective of this investigation was to find the best conditions of a forced convection rotary drying process applied to the drying of garment leather. Garment leather was chosen because it is a sort of clothing that by definition is soft and thin, very similar to textile clothing. Specific objectives have also been posed to assess the effect of the drying process on some subjective quality properties (softness, elasticity, colour, wrinkles, and sponginess) and a number of physical properties (humidity, area, tensile strength, extension, adhesion, and resistance to friction) of interest in the manufacture of garment leather.

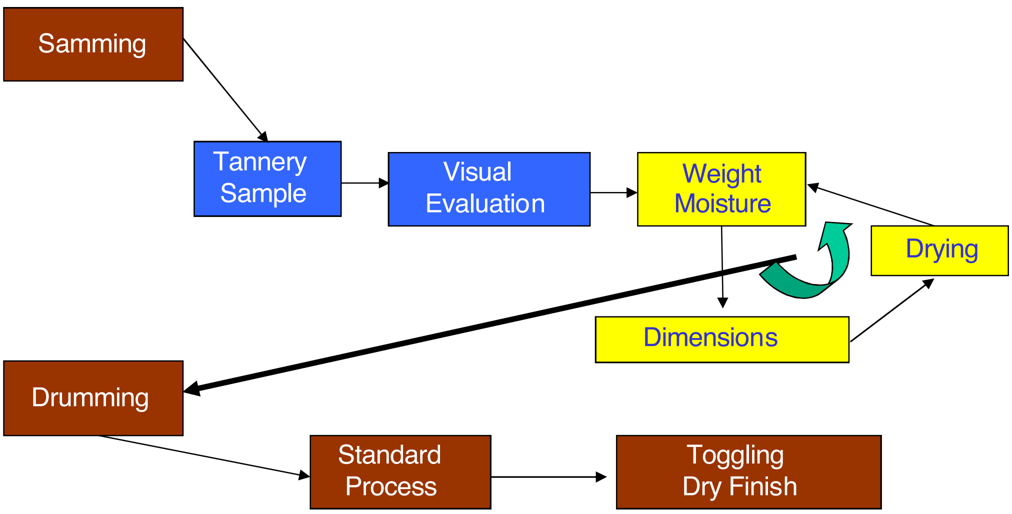

Figure 1. Methodology for the experiment.

2. MATERIALS AND METHOD

The forced convection drying procedure was performed in a small LP gas industrial tumble dryer of 11kg capacity by controlling the process parameters and monitoring environmental conditions of the air entering and leaving the equipment. Both physical and subjective quality properties of the finished leather were evaluated and compared to those of leather pieces dried by natural convection drying (hanging). Forced convection drying was performed to remove the initial moisture of the leather (~60%) to the expected level of the after-hanging drying process (~20%). The leather was characterized subjectively by a panel of four experts, two of them from CIATEC and the two others from external tanneries, everyone assessing: softness, elasticity, colour uniformity, wrinkles, and sponginess. Objective physical tests conducted in the lab were moisture, shrinkage, tensile and tear strength, and both adhesion and friction resistance of the finish were evaluated. The objective and subjective characterization was compared with respect to each type of drying process. Pelibüey pieces of leather were used from a tannery participating in the project named RM (Ruiz Moreno). The Pelibüey (also known as Cubano Rojo) is a breed of domestic sheep raised in the Caribbean, Mexico, and South America.[22] Figure 1 shows the methodology according to the relevant steps of the tanning process in regard to this investigation.

3. RESULTS AND DISCUSSION

Moisture reduction

After the natural convection hanging process, the expected moisture is 15-20%.[1,2] Table I shows the leather moisture values at different times and set-point temperatures in the tumbler dryer, showing the conditions where excessive moisture was removed from the leather. The handle of the leather skins at about 10% moisture was poor in regard to quality, which confirms the findings of *References* 2, 5, 6, 13, and 14. However, it was necessary to overdry the pieces in order to understand the drying process in the tumbler equipment and observe the stiffness of the pieces. Runs 5 and 6 confirmed that using the drying machine to reach the usual moisture target of about 15-20% results in an excessively stiff leather, too shrunken and wrinkled, especially at the edges.

TABLE I
Changes in the leather moisture as a function of time and drying temperature

Run 3	0'	30'	60'	85'	92'
		48°C	48°C	38°C	38°C
Moisture	55.5%	30.8%	10%	5%	1%
Run 4	0'	30'	60'	90'	100'
		38°C	38°C	38°C	22°C (T_{amb})
Moisture	62.8%	56.5%	40%	8.3%	1%

TABLE II
Changes in the leather moisture as a function of time and drying temperature

Run	Tumbler drying	Hang dry
7	0.4	0.37
8	0.4	0.43
9	0.393	0.405
10	0.45	0.36
Average	0.41	0.391

Calculated values are:
Initial humid weight over final dried weight (kg/kg)

As a result of those runs, it was decided to avoid drying the pieces only by tumbler drying, but to carry out the drying in two steps, the first one in the tumbler drying machine and the second one by natural hanging. Table II shows the drying level reached by means of both machine and hanging drying. It represents the ratio between the original weight and the final weight after each process (since the moisture is not actually evenly distributed in each piece of leather). The consistency of the final moisture of the runs is noted, the results are comparable, except for run 10 where 50% more pieces were dried whilst trying to scale up the process.

The drying system was equipped with both temperature and air humidity sensors. The instruments monitored both the ambient air around the dryer and the air current exiting the drying chamber (directed by a tunnel out of the laboratory). Both data allowed us to estimate the absolute moisture the air contains by means of the Groff-Gratch equation:[23]

$$\begin{aligned} \mathrm{Log}_{10}\, p_w = & -7.90298\,(373.16/T - 1) \\ & + 5.02808\, \mathrm{Log}_{10}(373.16/T) \\ & - 1.3816 \times 10^{-7}(1011.344^{(1-T/373.16)} - 1) \\ & + 8.1328 \times 10^{-3}\,(10^{-3.49149\,(373.16/T-1)} - 1) \\ & + \mathrm{Log}_{10}(1013.246) \end{aligned} \qquad (\mathbf{1})$$

with T, the absolute air temperature, in [°K] and p_w, the saturation water vapour pressure, in [hPa].

The concentration of water vapour in the air was calculated with equation (**2**):

$$\text{kg water vapour/kg dry air} = 0.018p_w/(0.029(P_T - p_w)) \qquad (\mathbf{2})$$

where P_T is the total pressure (which in Leon, Mexico averages 618.7mmHg = 82486.321 Pa).

During the tumble drying process there was a cyclical behaviour associated with the intrinsic temperature control of the equipment (a span of 5°C between on and off heating, shown by blue rhombus in Fig. 2). Run 10 was set at 38°C, so that the control turns off the heating at 38°C and turns it on at 33°C; the cycle repeats as long as the device is heating. In the tests, the heat provided dries out the leather so that the air exit temperature slowly increases (Avg Temp) whereas the air exit moisture decreases (Avg RH). The final section of the plot (about 2 hours) corresponds to a stage of stabilization of the drying process, a process without heat but only drumming with air circulating at ambient conditions. This is done to cool the leather samples, to suddenly stop the heat drying, the shrinking, and the wrinkling. Therefore there is a drastic decrease in the air exit temperature and an increase in the relative humidity; the former due to the fact that the remaining moisture is still evaporating taking the heat from the leather itself decreasing its temperature and also that of the air exiting the dryer. The air exit temperature increases again since there is an equilibrium reached between the leather moisture and the environmental conditions up to that of the ambient. The same phenomena occur when analyzing the ambient humidity, which increases towards the value of the environment.

The absolute humidity of the air exiting the dryer can be estimated (in comparison to the actual environmental conditions of temperature and humidity), Figure 3. This measurement was made so that we could build elements that would give a basis for stopping the drying process (Eq. **2**) without taking samples to monitor the leather moisture. In the test the initial weight of the skins was 9.091kg. From previous tests it was learned that the ratio of final to initial weight should be about 0.4 to leave the leather samples with desirable physical properties; therefore, the amount of water evaporated should have been 3.636kg in order to leave some moisture left to be evaporated by hanging (avoiding excessive stiffness). Figure 3 shows the calculated amount of water evaporated during the drying of 14 half skins (lower line, left axis). The drying process was stopped according to the dryness of the leather, *i.e.* when the water evaporation rate reached a constant value and the drying slope has a near zero value (upper line, right hand axis). The target moisture that should be reached may be about 30% to maintain a desirable set of physical properties. Therefore, the monitoring of the absolute moisture and its derivative with time (slope) is a reliable tool to use to assess the drying

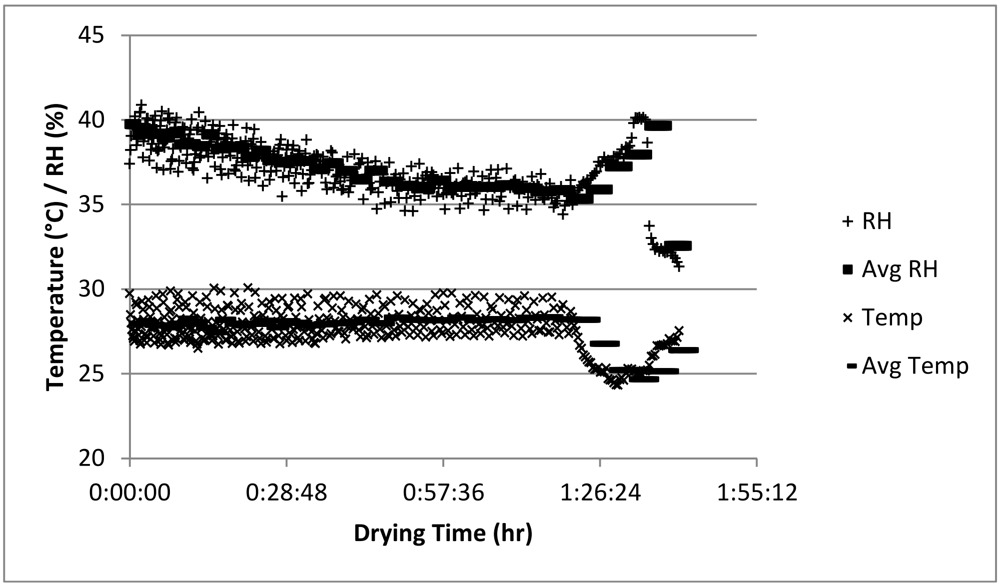

Figure 2. Behaviour of the air humidity and temperature at the exit of the dryer.

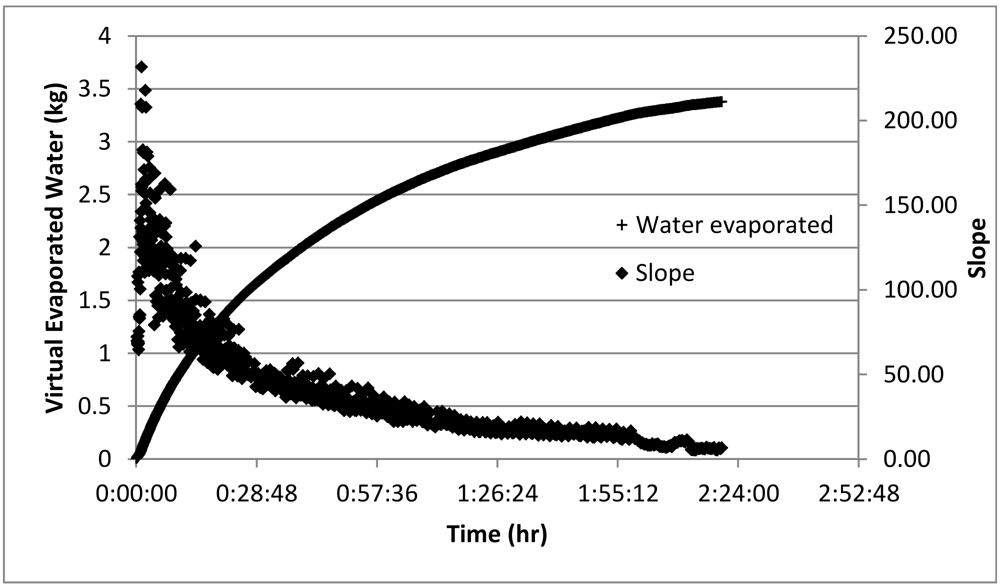

Figure 3. Virtual evaporated water during the forced convection drying process

rate of the leather pieces so that this criterion can be used to stop the drying process. The next item for research is to identify the moisture target (slope) for different sorts of garment leather under different ambient conditions. The experiences of the many drying tests from the view of wrinkles and area loss of the leather samples also leads us to suggest that the tanner should perform an incomplete tumbler drying of the samples to optimize the costs. It is important to also mention that the operative personnel in the tanneries participating in the project (Tanneries Tribis and Ruiz Moreno) were unable to differentiate between leathers dried by either method.

Area loss

An area reduction occurs in the leather during the drying process by forced convection; similarly, some shrinkage takes place when the leather is dried by hang drying (natural convection drying).[3,4] Figure 4 shows the method chosen to measure the leather area before drying, as the area cannot be normally measured as the wet leather is not suitable for the area measuring machines typically used in tanneries. Thus, each piece was measured and marked at length and width, actually mimicking a rectangle, but considering the most critical dimensions that change.

TABLE III
Dimensional changes of the pieces (average)

	Tumbler drying		Hang dry	
	% average shrinkage after drying			
Lot	Length	Width	Length	Width
3	85.89	85.06		94.51
4	88.33	80.75	91.47	
5	89.63	82.63	93.35	80.86
6	89.88	81.11	92.92	82.50
7	87.26	85.56	92.99	90.26
8	86.87	83.85	93.72	96.51
9	88.15	81.88	94.22	92.84
10	89.80	85.14	94.28	94.40
AVG	**11.77**	**16.75**	**6.72**	**9.73**

Calculated figures are % of original size

TABLE IV
Dimensional changes of the pieces (average) after toggle drying and edge trimming

	Tumbler drying			Hang dry	
	% average shrinkage after drying				
Lot	Length	Width	Lot	Length	Width
4	95.85	98.06	2	83.27	101.95
5	95.02	103.84	3	101.30	108.45
6	99.02	100.73	8	102.25	104.76
7	95.48	95.97	**AVG**	**95.60**	**105.05**
9	99.11	94.12		**AREA**	**10042.78**
AVG	**96.89**	**98.54**		**AREA RATIO**	
	AREA	**9547.54**		**95.07 %**	

Calculated figures are % of original size

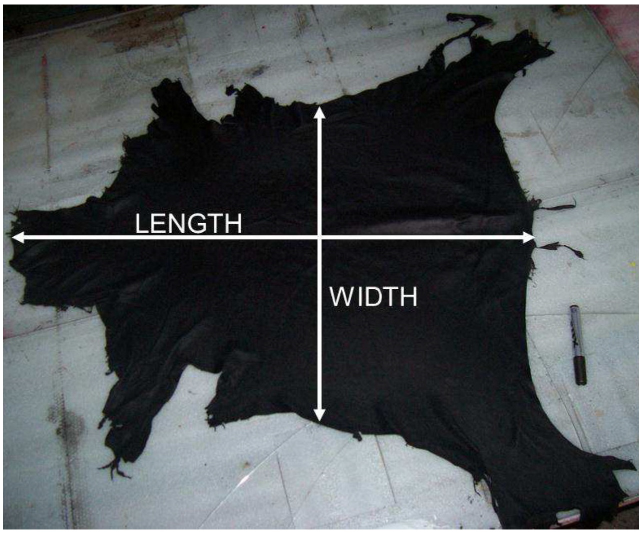

Figure 4. Contraction area criteria.

Figure 5. Undesirable wrinkles in the garment leather (top) and a good appearance (bottom).

Table III shows the comparison of the initial dimensions to the final ones, showing a reduction in size of about 16% in width and 9% in length when only the drying processes are considered. Hanging drying also triggers area reduction. It was observed that twice as large a shrinkage takes place comparing forced tumbler drying against hanging.

A typical tanning process includes a further toggling drying process at high temperature to gain some of the area lost.[13,14] This project assessed this fact and found objectively that the toggling step after hanging drying causes not only the garment leather to almost

TABLE V
Physical properties of the leather (H = hang dry, T = tumbler drying), and subjective characteristics of the leather quality (5 = high, 1 = low)

Judge (CIATEC)	Víctor Ramírez				Pedro Cruz			
	SAMPLE							
CHARACTERISTIC	1T	3T	4H	6H	1T	3T	4H	6H
Smoothness (5 = high, 1 = low)	3	3	2	2	2	1	2	1
Elasticity (5 = high, 1 = low)	2	2	2	2	2	3	2	3
Colour (5 = good, 1 = bad)	1	1	1	1	1	1	1	1
Wrinkles (5 = too many, 1 = a few)	1	1	1	2	1	1	2	2
Sponginess (5 = high, 1 = low)	1	1	1	1	1	1	1	1
Judge (CIATEC)	Fco. Javier López				Abraham López L			
	SAMPLE							
CHARACTERISTIC	1T	3T	4H	6H	1T	3T	4H	6H
Smoothness (5 = high, 1 = low)	3	4	4	3	4	3	3	3
Elasticity (5 = high, 1 = low)	5	5	5	5	5	5	5	4
Colour (5 = good, 1 = bad)	4	4	4	4	5	5	5	5
Wrinkles (5 = too many, 1 = a few)	4	2	2	3	1	1	1	1
Sponginess (5 = high, 1 = low)	2	3	4	3	4	3	4	3

completely recover its original area but also that there is an area gain of 0.4% (Table IV). Comparatively, it can be stated that tumble drying by forced convection reduces by up to 5%, the area of the leather with respect to the natural convection hanging drying process (these results were obtained after the edge trimming, another unavoidable tanning step where some area is lost, see Fig. 5). This is important because the leather is sold by area from which the profit is made.[13] If some area is lost, in compensation, productivity may be increased from hanging drying of about 12 hours to tumbler drying of about 2.5 hours, a productivity ratio of almost 5, a profit well above that corresponding of the 5% of area lost, independently of whether it is the rainy season or not.

Physical properties

The collected evidence, from the subjective and objective tests, did not show statistically significant differences, while the subjective evaluation marks little differences made by the panel of four experts grouped from CIATEC and industry (results analyzed row by row). Table V shows the results of the subjective properties assessment, which results differ in criteria between CIATEC and industry. However, what must be observed are the qualifications between the pieces of leather dried by means of the two methods (tumble *vs* hanging). In this regard little differences are observed, meaning that experts in the field could not distinguish between a piece dried by hanging against one dried by forced convection, except for the wrinkles (before the evaluation, the experts were not advised about the drying method of each piece). On the other hand, operatives in the tannery are unable to distinguish which leathers come from hanging or tumble drying.

Regarding the objective physical properties, there are no standards for some characteristics because the experimentation was on garment leather. This is a thinner leather than that used for shoe manufacturing which has well defined physical properties. Because of this, garment leather is generally compared to lining, which has most of the properties defined in regard to shoe leather and it is more documented than leather for clothing (Table VI).

Some variability in the properties is observed when each piece is compared to the others; however, when a standard exists the values are well above it. The design configuration of the forced convection tumble dryer provides only one detectable property that should be taken care of: the tendency for the formation of wrinkles (as shown in Figure 5, left, wrinkles, and a smooth, quality leather, right). This investigation has led to the conclusion that, to minimize wrinkling and shrinkage, tumble drying must be partially employed and then followed by hang drying to stabilize the moisture of the leather to the ambient conditions, a step that takes around 2 hours to achieve.

TABLE VI
Physical properties of the leather (H = hang dry, S = forced drying, na = not available)

	Hang dry			Tumbler drying			
	1H	2H	3H	5S	6S	7S	STD
Adhesion, N/mm	0.3	0.35	0.6	0.4	0.45	0.35	na
Tear, Kg	6.8	6.3	3.4	5.0	8.3	5.1	3
Thickness, mm	0.7	0.73	0.69	0.8	0.96	0.87	–
Tension, Kg	187	441	137	244	350	189	100
Elongation, %	56.2	50.5	57.2	73.6	74.2	53.7	40

4. CONCLUSIONS

In general, the tests carried out on garment leather pieces dried by two different drying methods show a good feasibility of the technology of forced convection tumble drying in removing moisture. It can be used to dry garment leather. It has the main disadvantages of area loss and wrinkling, compared with leather processed by natural convection drying. Yet, advantages of the method include a more elastic and flexible leather. In terms of productivity, tumble drying significantly reduces the drying time up to a factor of four, and easily compensates for any loss represented by the 5% area loss.

The drying rate directly affects the physical properties of the garment leather. While the forced convection drying time can be reduced to 2.5 hours, the more valuable property of the leather is affected: the area. The reduction of 5% of area represents a disadvantage on the implementation of the technology, but other properties such as softness, elasticity and fluffiness are improved. The physical properties remain within the standard values, regardless of the type of drying. One advantage has been elucidated in the two tanneries where work has been done: if the force dried leather is not identified, operators and vendors are unable to differentiate one leather from the other, *i.e.*, the differences are subjective and can, on that basis, not be a major disadvantage of using forced convection to replace natural convection in the drying of garment leather. The productivity of the tannery may be increased since the overall manufacturing process can be reduced. Therefore the manufacturer may double the sales, increasing the profit amortizing the cost of the area lost.

5. ACKNOWLEDGEMENTS

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