Evaluation of the Energy Savings when using Vacuum Dryers with Total Thermal Energy Recovery in Tanneries

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Abstract

One of the operations with a large impact in the electrical consumption of a tannery is the drying of the leather. This paper compares the energy efficiency of two different types of vacuum dryers working at low temperature. The objective is to work at low temperature to obtain leather with higher quality. In particular, a traditional vacuum dryer is compared with a vacuum dryer modified to work at low temperature with low energy cost and with considerable economical savings.

Resumen

Una de las operaciones con gran impacto en el consumo eléctrico de una curtiembre es el secado de la piel. En este trabajo se compara la eficiencia energética de dos tipos diferentes de secadores al vacío trabajando a baja temperatura. El objetivo es trabajar a baja temperatura para obtener cueros de mayor calidad. En particular, un secadero al vacío tradicional es comparado con un secadero al vacío modificado para funcionar a baja temperatura con bajo costo energético y considerables ahorros económicos.

Introduction

One of the operations with more impact in the electrical consumption of a tannery is the drying of the leather. During drying, besides the loss in water, other processes take part. These are migration of non fixed materials (non tannins, fat, dying chemicals, etc.), contraction of the leather surface, bindings formation (fixation of materials in the collagen structure), and modification of the isoelectric point[1].The drying system used strongly influences the quality of the final leather; working at low temperatures improves significantly the organoleptic characteristics of the final product[2-9].

There are several methods used nowadays for drying leather. Traditionally, leather was dried hanging the wet leather and letting it travel around the producing site, the tannery. Nowadays, most of the leather is dried in drying tunnels, which are automatically controlled, setting the duration of the drying process, temperature and humidity[3]. Here the water leaves the leather from both sides and evaporates from the surface of the leather, therefore soluble non fixed materials remain on the surface of the leather. If the process is slow and long, some of these products can diffuse inside again through the humid fibers, giving high quality leather. If the process is too fast, soluble materials stay in the surface of the leather, changing the color of it and the physical properties of the surface[4-5].

A new method not used very much is lyophilization, usually used to dry pharmaceutical products with very high added value and that changes their characteristics when heated up. Lyophilization is done at temperatures lower than 0ºC during very long periods of time. The industrial machinery for this drying system are very expensive and with high maintenance costs[10].

Within the several methods of drying leather, vacuum drying has the advantage of being very fast, and allowing high production rates. Vacuum drying can be done at different temperatures, but the higher the temperature, the poorer is the final quality of the leather. Due to this, it is preferred to dry leather at low temperatures that is using temperatures lower than 40ºC[4]. Nowadays, the industry also has the challenge to save water in its processes. This is due to the increasing cost of water and to environmental reasons. This has lead to the development of new dryers which make possible to dry leather at low temperatures, spending less amount of water, and with more recovery of thermal energy[7] than the one used nowadays in tanneries. In this paper an economical evaluation of the energy savings when using vacuum dryers modified in tanneries compared to traditional vacuum dryers is presented.

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Vacuum dryers performance
Vacuum drying of chromium tanned leather is a common technology nowadays. It consists in a flat metal table (usually stainless steel) hermetically closed with another metal table. Vacuum is produced inside the space between both metal tables (where the wet leather is located) and water is evaporated and leather dried[6].

Wet leather with humidity up to 50% is placed over the metal table, and is heated up to 40 to 60ºC. Vacuum is produced for 2 to 5 min until the humidity is between 25 to 30%[11].

The grain of the leather is set directly over the heated metal table and is the side of the leather which dries first. Total drying is not possible because heat transfer inside the dried leather is very poor and the duration of the drying process would be too long. Vacuum drying is based in conduction heating of the leather. The water is evaporated from the leather as fast as possible and at the lowest temperature possible. For example, if the evaporation of the water needs to be done at 32-35ºC in 3 to 4 minutes, it is necessary to work at around 12 mbar[8].

The vapor generated in the system needs to be removed to maintain the vacuum in the system. Due to environmental and economical reasons, this vapor is reused in the tannery; therefore it needs to be condensed. The vapor temperature is about 20ºC lower than the metal table temperature, and to be condensed it needs to exchange energy with water in a heat exchanger at a temperature at least 5ºC lower. Therefore, in the given example, it is necessary to use a condenser with running water at 5ºC. Since usually tap water is used for this purpose, this water needs to be cooled with a chiller, and chillers have a high investment cost, high energy consumption and high maintenance cost. Of course, the higher the drying temperatures, the higher the cooling water temperature in the heat exchanger, therefore, less energy is used for cooling. As already mentioned above, working at higher temperatures gives leather with lower quality.

An alternative to the use of a chiller is to modify the traditional design of the vacuum dryer to increase the pressure of the vapor obtained from the leather before condensing it. When increasing the pressure of a gas, its temperature increases and, therefore, the temperature of the water used for the condensation can be higher. The pressure of the vapor is increased through a mechanical compressor or through a vapor injector (Figure 1). Now, the vapor can be condensed with water at higher temperature (around 20ºC). The cooling water can be tap water in cold climates, water coming from a refrigeration tower in a closed system, or the same recovered water after being cooled down in a refrigeration tower. Figure 2 shows a sketch of the traditional vacuum dryer without modification. Depending on the climatic conditions, in some areas like the Mediterranean area, it is necessary to install a refrigeration tower to cool down the condensation water. Nevertheless, the whole process uses less energy than the traditional vacuum dryer.

Another factor to be considered is the heating of the vacuum plates. The water used to dry the leather goes through a steam heat exchanger and is pumped back to the plate (Figure 3). Therefore, the water inside the dryer is always the same, circulating within a close loop. The steam used to maintain the plate hot is the same than in the original vacuum dryer. Modern vacuum dryers can work at low temperatures drying with very short time, but they can also work as a traditional dryer, using higher temperatures or longer periods of time. The lower the working temperature and the longer duration of the drying process, the higher will be the energy consumption.

Experimental section
In this paper, a tannery using a vacuum dryer of five tables is considered as reference drier. Each table has a surface of 7 m x 3 m. This vacuum dryer was used to dry chromed leather with an initial humidity of 50%. The final humidity of the leather was 25%. The working temperature was 35ºC, optimum to have a good quality in the final product. To achieve this temperature, a chiller has been added to the system. The drying duration was 4.5 minutes.

Here, this equipment is substituted by one of the new vacuum dryers working with total thermal recovery described above. The number of tables and surface area are the same, and is installed together with a refrigeration tower. All the other peripheral equipment is the same. The kind of dried leather and the working conditions (temperature, time and pressure) were the same. The aim of the substitution of the equipment is to produce leather with the same quality, but with lower energy and water consumption. In the economic evaluation, the water savings are not considered, because in many companies water is reused.

A team of five experts examined the leather once dried and compared the organoleptic properties of the leather dried with the conventional vacuum dryer and with the modified model. The basic data of the conventional vacuum drying system and of the modified vacuum drying system is presented in Table I.

RESULTS AND DISCUSSION

As expected, because the working conditions did not change, the experts did not find any difference between the dried leather with the conventional vacuum dryer and the leather dried with the modified vacuum dryer.

The economical evaluation of the new technology is basically given by the savings in energy used. Table II presents the annual energetic savings obtained with the new technology. The annual energy savings obtained are 162,884 kWh/year, which means 14 TEP/year. This means 82% savings. Nevertheless, the modified vacuum dryer need twice as much steam, meaning 240,800 kg of steam per year, an increase of 100%.

The economic evaluation is done with the energy prices in Spain. If the energy savings are 162,884 kWh/year, and the average price of the electrical energy is 0.1047 €/kWh, the savings when using the new technology are 17,054 €/year. The price for steam production is 0.04 €/kg of steam. This means an annual cost of 9,632 €, having final savings of 7,422 €/year.

A conventional vacuum dryer costs about 200,000 €, and the vacuum dryer modified costs 260,000 €, therefore, this new technology means an additional investment of 60,000 €.

With the savings calculated above and under de assumptions presented here, the use of this technology has a pay-back period of 97 months (8 years approximately).

The main advantages of the modified vacuum dryers are:

- Capacity of working at very low temperatures
- High versatility when working in conditions energetically favorable for thermal recovery. It is possible to perform a total recovery of the condensation heat and of excess heat generated by the compressor in all operating conditions between 30ºC and 90ºC.
- Only a refrigeration tower is needed to cool down the water used to condense the steam produced in the leather drying process. This means important energy savings because if the conventional vacuum dryer wants to be used to dry at low temperatures, it needs a chiller since the steam has to be condensed at a much lower temperature.
- Because the circuit is simpler than the traditional vacuum dryers' installations, maintenance costs are very low. Equipment not used here are chillers and heat pumps.

All these advantages are translated into energy and water savings, meaning economical savings.The main disadvantage of this technology is the need of enough steam. Because of the steam ejectors, the minimum pressure of the steam needed is 6 bar. This new drying system is quite new, but it has already been successfully installed in Spain, Italy, Japan and Russia.

CONCLUSIONS

The calculation performed shows that the technology implemented in the new vacuum dryer model allows drying leather at low temperature with less energy consumption than the traditional models that work at low temperatures using a chiller. This allows obtaining leather with higher quality at a lower cost.

TABLE I
Basic data of the conventional and a modified vacuum drying system.

Reference	Traditional model	Modified model
Number of tables:	5	5
Metal table surface	7000 x 3000 mm	7000 x 3000 mm
	Power (kW)	
Vacuum pump	24	20.8
Water pump	5	4.4
Hydraulic pump	6	6
Chiller + water pump for the chiller	196	10.4
Total	231	41.6
kg/h steam	280	560

TABLE II
Annual costs

Field 1	Traditional model	Modified model
Annual working hours (h/year)	860	860
Annual electricity consumption (kWh/year)	198660	35776
Electricity savings (kWh/year)	---	162884
Steam annual consumption (kg/year)	240800	481600
Steam savings (kg/year)	240800	---

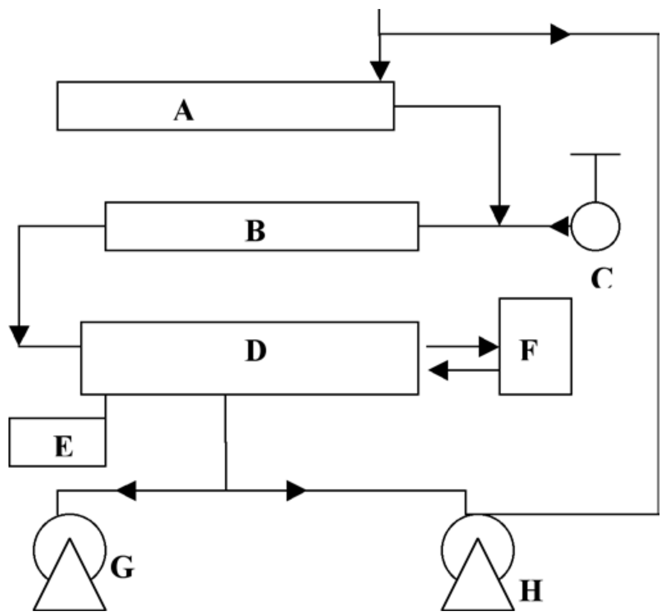

Figure 1: Sketch of a modified vacuum dryer. A = Steam collector of the dried leather, B = Steam ejector (Vacuum generator), C = Steam injector, D = Heat exchanger (condenser), E = Condensate tank, F= Refrigeration tower, G = Vacuum pump (keeps vacuum in the heat exchanger), H = Pre-vacuum pump (extracts most of air when the dryer is heated)

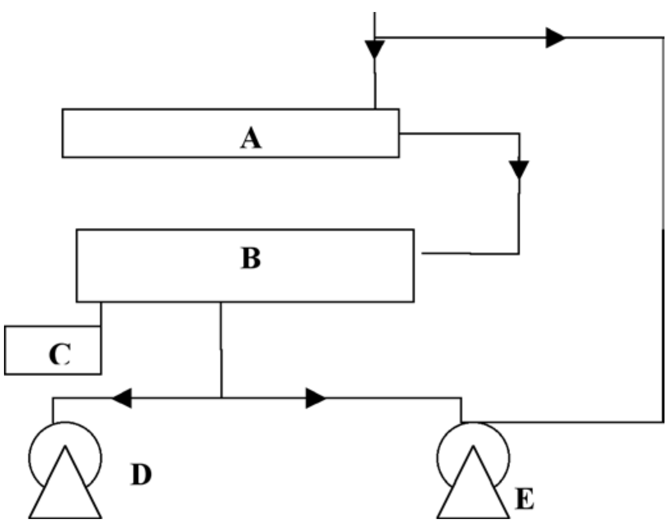

Figure 2: Sketch of a traditional vacuum dryer. A = Steam collector of the dried leather, B = Heat exchanger (condenser), C = Condensate tank, D = Vacuum pump (keeps vacuum in the heat exchanger), E = Pre-vacuum pump (extracts most of air when the dryer is heated).

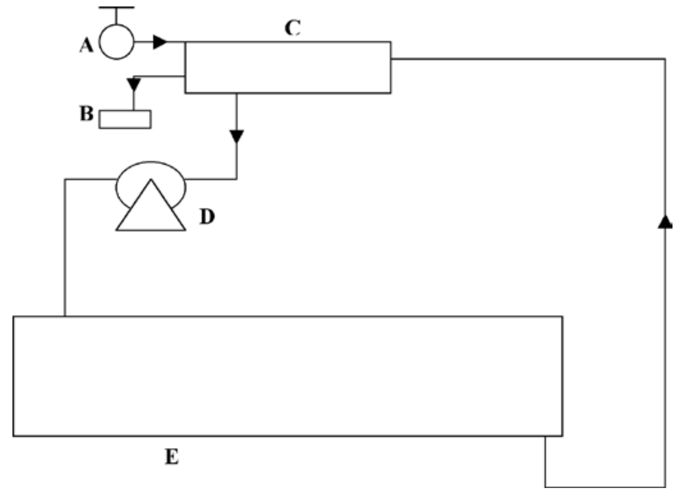

Figure 3: Sketch of the closed water loop to heat up the vacuum dryer. A = Steam valve, B = Condensate tank, C = Steam heat exchanger (heat up the water going back to the table, D = Bomba d'aigua (circulates the water of the table), E = Metal table.

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