# EFFECT OF HUMIDITY AND TEMPERATURE ON DRYING OF NATURAL RUBBER

**Siby Varghese, Treesa Cherian and Baby Kuriakose**
Rubber Research Institute of India, Kottayam – 686 009, Kerala, India.

*Submitted: 25 September 2001 Accepted: 30 July 2004*

---

Varghese, S., Cherian, T. and Kuriakose, B. (2004). Effect of humidity and temperature on drying of natural rubber. *Natural Rubber Research,* **17**(1) : 53-59.

The effect of temperature and relative humidity on drying of three forms of natural rubber *viz.*, rolled latex coagulum, latex coagulum crumb and field coagulum crumb was studied by recording the percentage reduction in moisture content with time. Influence of the surface area on drying was demonstrated using yeast treated latex coagulum. Results indicated that larger portion of the drying time was for the second phase of drying (below 10% moisture), which involves diffusion of moisture from the coagulum. The rate of diffusion is influenced more by temperature of drying than by relative humidity.

Key words: Diffusion, Drying, Moisture content, Natural rubber, Relative humidity, Sheet rubber.

---

## INTRODUCTION

The method of drying employed for a particular material depends on its characteristics. However, there are certain fundamental considerations which are applicable to all drying methods. If a very wet solid is exposed to air, it immediately commences to lose water by evaporation. The rate of evaporation depends upon the condition of the surrounding air and the surface area of the material exposed. As long as the surface remains wet the rate at which water is removed is independent of the moisture content of the solid (Piddlesden, 1936). Thus, if the external conditions are maintained constant, drying proceeds at a constant rate, and while this persists, the temperature of the solid surface will be the wet bulb temperature of the air (Lowery and Kohman, 1927; Sherwood, 1929; Newman, 1931). This 'constant rate period' continues until dry patches are formed on the surface. At this point drying enters the 'falling rate' period and the water content is called 'critical water content'. This period in turn may be divided into two zones. The first is the zone of unsaturated surface drying in which external atmospheric conditions are still important but are modified by the consideration that, as drying proceeds, the area of effective wet surface diminishes. In the second zone, internal liquid diffusion takes place. At this stage, the nature of the material being dried is of major importance and the condition of the surrounding air has little or no effect (Piddlesden, 1936; Daynes, 1932). The rate of drying is thus divided into at least three zones, each controlled by different sets of variables.

During drying, the layer of air in contact with the wet surface soon becomes saturated with moisture, and evaporation is therefore limited by the rate at which the moisture diffuses through the layer. This in

---

Correspondence: Siby Varghese (E-mail: siby@rubberboard.org.in) turn, depends upon the thickness of the layer, which may readily be reduced by increasing the air velocity across the surface (Sherwood, 1931; Sekhar, 1958). Thus, for rapid evaporation, not only must the air velocity be high, but the relative humidity must also be low. These conditions may be achieved by using a constant stream of fresh air at high temperature. The surface area must also be as large as possible.

Unsaturated surface drying commences when dry patches begin to occur on the surface and continues until the rate of diffusion becomes the limiting factor. During this phase, the area of wet surface and consequently the drying rate, usually decreases approximately in direct proportion to the moisture content (Philpott and Walker, 1955; Gale, 1959).

In the internal liquid diffusion zone, the rate of diffusion of moisture from the interior to the surface of a wet slab decreases with decrease in water content of the material. A second critical point therefore occurs when the rate of diffusion can no longer keep pace with the rate of evaporation from the surface. When the moisture content is below the critical value, the rate of diffusion controls the rate of drying. The rate of drying under these conditions may therefore be expressed as a Fouries series (Piddlesden, 1936)

$$dM/dt = k.\ d^2M/ds^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

M is the moisture content

t is the time

s is the thickness of the material

k is the diffusion content and

d is the rate of drying

From this equation the value of the diffusion factor k, which is proportional to the rate of drying, is determined by the permeability of the particular substance being dried and the temperature at which drying is carried out.

It is observed that for rapid drying, sheet rubber should be as thin and as porous as possible and temperature used should be high throughout. In the early stages, high air velocity will be advantageous. There are obviously practical limitations to the applications of these conditions. Unduly high temperature will damage the sheet by blistering. If the sheet is machined too thin, the cost of machining, the space required in the smoke house and the difficulties in handling are more. Finally, the use of high air velocities, and at the same time maintenance of an adequately high temperature, would necessitate larger expenditure on energy, unless some mechanical system for the recirculation of air is used (Gale, 1959; Sekhar, 1958).

Traditionally, rubber sheets are dried in smoke houses where firewood is used as energy source. Later, efforts were made to utilize the freely available solar energy for the purpose of drying sheet rubber (Nair *et al.*, 1998; Tillekeratne *et al.*, 1995; Yogaratnam *et al.*, 1998). Jayasuriya *et al.* (2000) made an effort to correlate the drying conditions of sheet rubber with its technological properties. Auria *et al.* (1991) examined the internal structure and water transfer during the drying of sheet rubber whereas drying of granular form of natural rubber has been examined by Nanon *et al.* (1995). So far there has been no report on the combined effect of temperature and humidity for the drying of different fresh forms of natural rubber coagulum. The subject is more important as the energy sources (firewood, electricity and solar panels) are becoming more and more expensive.

The objectives of the present study were to examine the effect of humidity and temperature on the drying of different forms of rubber coagulum and to work out the possible combinations of temperature and humidity so as to dry the rubber in the minimum possible time without affecting its properties.

## MATERIALS AND METHODS

The materials selected for the study were rolled latex coagulum, latex coagulum crumb and field coagulum crumb. Rolled latex coagulum was prepared as per the standard norms, with a final thickness (after drying) of 3 mm. Crumbs (produced from latex and field coagulum) having 5 mm diameter, were collected from the Pilot Crumb Rubber Factory of the Rubber Research Institute of India. The drying of the materials was monitored using a Humidostatic Cell, model CU 10-35 (ATS FAAR, Italy) in which any combination of temperature and RH can be set. The three types of coagula were dried at temperature levels of 60 and 80°C and relative humidity ranges of 25, 40 and 60 per cent. Loss of moisture of the material is determined by weighing the samples accurately at definite time intervals and calculating the difference with respect to the initial weight, till the moisture in the materials was less than 1.0 per cent. Drying was assumed complete when there was no opaque patch in the sheet.

Porous rubber was produced by treating the field latex with yeast and sugar. Field latex (1 kg dry rubber) was treated with 0.5 g of yeast and 8 g of sugar. It was then kept overnight for forming and coagulation. The autocoagulated porous material was cut into circular discs (3 cm) without disturbing the porous structure (John, 1966; John and Pillay, 1971; Roudeix, 1985).

## RESULTS AND DISCUSSION

### Rolled latex coagulum

The drying curves were prepared by plotting moisture content against time. In Fig. 1, drying curves of rolled latex coagulum at 60 and 80°C, at a fixed relative humidity level of 25 per cent, are given. Irrespective of the temperature, loss of water from the material followed the same pattern except that at high temperature drying was faster. The rate of drying was high during the initial few hours when surface evaporation was the major process, the slope of the curve being steep and practically straight. Drying was slow during the final stages. At a particular moisture content onwards rate of drying will be determined by diffusion and this point was therefore taken as the second critical moisture content (Piddlesden, 1936). It was obvious from the curve that

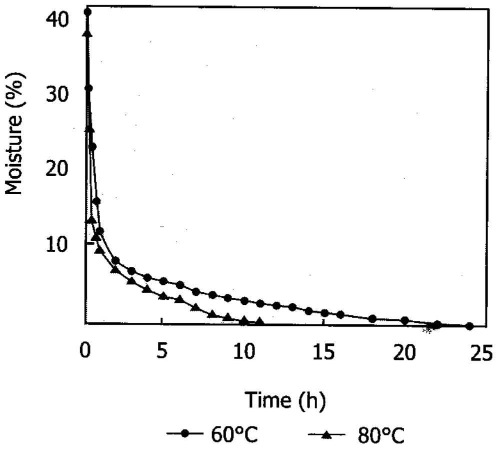

Fig. 1. Drying of sheeted coagulum at 25% relative humidity

the diffusion-controlled portion of the drying occupied the larger part of the total drying time. The decrease in moisture content with time for rolled latex coagulum at 40 and 60 per cent humidity also followed a pattern similar to that at 25 per cent and hence is not presented. It can be seen (Table 2) that increase in temperature has very little effect on the initial drying (surface evaporation) except at high humidity. However, at a fixed temperature, surface evaporation was delayed at high humidity. This is because the layer of air in contact with the surface soon became saturated with moisture and evaporation was limited by the rate at which the moisture could diffuse through this layer (Sherwood, 1931). The time taken for final drying (below 10% moisture) was almost independent of humidity at lower temperatures, whereas at the higher temperatures lower humidity favoured faster drying.

## Drying of latex coagulum crumb

The drying curves for latex coagulum crumb are given only for the 25 per cent humidity as the nature of the curves of the other two humidity levels was identical. At all humidity levels, as temperature increased, there was a reduction in the total drying time. As in the case of sheeted coagulum, here also the major portion of the drying time used was for the diffusion-controlled process (Table 1). In the initial drying zone (surface evaporation), temperature had very little effect especially at low humidity. The sudden decrease in rate occurred as the drying proceeded through the diffusion-controlled process. It was also found that humidity had a noticeable effect on the drying of latex coagulum crumbs only at low temperatures in the initial drying.

## Drying of field coagulum crumb

Drying curves of field coagulum at different humidity levels (25, 40 and 60%) were studied and the curves at 25 per cent humidity are given in Fig. 3. The pattern of the curve was similar to that for latex coagulum crumb. It can be seen that there was a decrease in the time for initial drying with rise in temperature. However, in the case of field coagulum crumb, the initial drying took

Table 1. **Time required for the drying of raw rubber to different stages**

| Material and relative humidity (%) | Time for initial drying, up to 10% moisture (h) | | Time for final drying, below 10% moisture (h) | | Total drying time to below 1% moisture (h) | |
|---|---|---|---|---|---|---|
| | 60°C | 80°C | 60°C | 80°C | 60°C | 80°C |
| Rolled latex coagulum | | | | | | |
| 25 | 1.4 | 1.3 | 17.6 | 6.7 | 19.0 | 8.0 |
| 40 | 1.5 | 1.3 | 16.5 | 6.7 | 18.0 | 8.0 |
| 60 | 2.7 | 2.0 | 17.3 | 10.0 | 20.0 | 12.0 |
| Latex coagulum crumb | | | | | | |
| 25 | 2.8 | 2.0 | 19.5 | 6.0 | 22.3 | 8.0 |
| 40 | 3.0 | 1.6 | 18.2 | 6.7 | 21.2 | 8.3 |
| 60 | 7.0 | 2.5 | 19.5 | 8.5 | 26.5 | 11.0 |
| Field coagulum crumb | | | | | | |
| 25 | 7.0 | 3.0 | 21.0 | 7.0 | 28.0 | 10.0 |
| 40 | 6.0 | 4.2 | 18.0 | 8.8 | 24.0 | 13.0 |
| 60 | 10.0 | 4.5 | 21.0 | 8.5 | 31.0 | 13.0 |

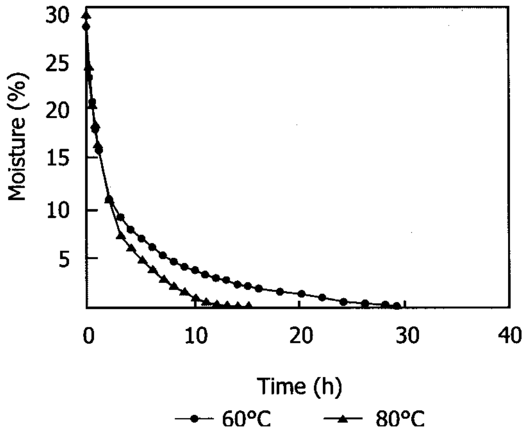

Fig. 2. Drying of latex coagulum crumb at 25% relative humidity

much more time compared to the latex coagulum crumb. However, the diffusion-controlled portion was more prolonged compared to that for the other two forms of rubber. This may be due to the fact that the slow diffusion process was further delayed by the impurities present in the field coagulum. Besides, the total time for attaining less than 1 per cent moisture (diffusion controlled) was also longer though field coagulum was expected to be more porous than fresh latex coagulum due to spontaneous coagulum and liberation of gas through bacterial action, the former usually has a dried film of rubber on its surface, which is less permeable than the latter. This may be the reason for the longer time required for diffusion for controlled drying of field coagulum.

At high humidity (60%), there was an abrupt increase in the initial drying time especially at low temperature. The rise in temperature also considerably increased the diffusion rate, which resulted in a lower drying time.

Based on the results of the above study, possible combinations of humidity and temperature were tried for each type of coagulum so as to reduce the total drying time. The selected combinations are given in Table 2. For rolled latex coagulum, the combination of temperature and humidity for both the initial and final drying was 60°C and 40 per cent respectively for which the total drying time was 18 h. When the final drying temperature was increased to 80°C, the total time required was half. The time for the initial drying being the same in both cases, reduction in the drying time was significant in the diffusion controlled process. However, drying rolled coagulum at high temperature (80°C) resulted in blister formation. For latex coagulum crumb, the ideal combinations of temperature and humidity were 80°C and 40 per cent respectively. The total drying time involved was 8.3 h. For field coagulum crumb, at 80 per cent humidity and at a temperature of 80°C, the total drying time was 13 h. However, a reduction in humidity level from 60 to 25 per cent in the final drying resulted in a total drying time of 10 h. Though other combinations

Table 2. **Combinations of humidity and temperature proposed for the drying of different forms of rubber**

| Material | Initial drying | | Final drying | | Total drying time (h) |
|---|---|---|---|---|---|
| | Temperature (°C) | Humidity (%) | Temperature (°C) | Humidity (%) | |
| Rolled latex coagulum | 60 | 40 | 6080 | 4040 | 188.2 |
| Latex coagulum crumb | 80 | 40 | 80 | 40 | 8.3 |
| Field coagulum crumb | 80 | 60 | 8080 | 2560 | 1013 |

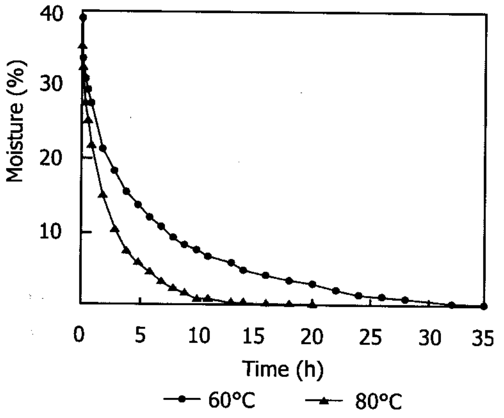

Fig. 3. Drying of field coagulum crumb at 25% relative humidity

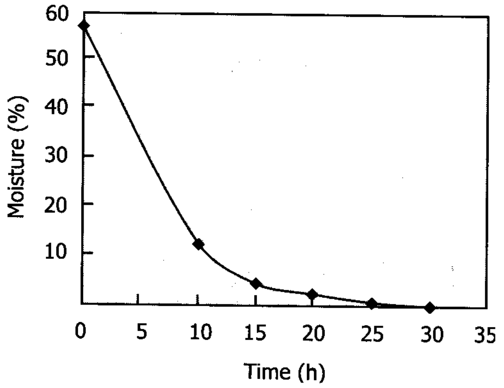

Fig. 4. Drying of yeast treated latex coagulum at 80°C

of temperature and humidity were tried for the drying of latex coagulum crumb, the total drying time was still higher. Hence a modification of the material by fermentation so as to make it more permeable to moisture was attempted.

**Assisted biological coagulation**

As suggested in Equation 1, the biologically coagulated rubber becomes more permeable to water. The drying curve of such a material is shown in Fig. 4. The diffusion controlled drying was faster because of the porous nature of the material. The total drying time of the material was only 2.5 h at a temperature of 80°C and humidity 60 per cent. It was also noted that the properties of the rubber dried using this technique were comparable to those processed by the conventional method, as was evident from its Wallace plasticity, Po (51) and plasticity retention index, PRI (76) values.

## CONCLUSION

The major part of the drying time for rubber is for the diffusion controlled process. Modification of the material to make it porous or rise in temperature can bring in an increase in the diffusion rate, which would finally result in an appreciable reduction in drying time. Time taken to dry the porous coagulum prepared by treatment with yeast is very short, and gives comparable raw rubber properties.

## REFERENCES

Auria, R., Benet, J.C., Cousin, B. and Sainte-beuve, J. (1991). Drying of natural rubber in sheet form: Internal structure and water transfer. *Journal of Natural Rubber Research*, 6(4) : 267-280.

Daynes, H.A. (1932). The measurement of water absorption by rubber. *India Rubber Journal*, 84 : 376-382.

Gale, R.S. (1959). A survey of factors involved in an experimental study of the drying of sheet rubber. *Journal of Rubber Research Institute of Malaya*, 16 : 38-64.

Jayasuriya, M.M., Mithrananda, K.M.U., Yapa, S., Ratnayake, U., Siriwardena, S., Kumara, Liyanage, G., Kurupu, R. and Wejesekara, M. (2000). Effects of drying conditions on the technological properties of sheet natural rubber. *Journal of Rubber Research*, 3(3) : 185-192.

John, C.K. (1966). Biological coagulation of *Hevea* latex using waste carbohydrate substrates. *Journal of Rubber Research Institute of Malaya*, **19** : 286-289.

John, C.K. and Pillai, N.M. (1971). Improvements to assisted biological coagulation of *Hevea* latex. *Journal of Rubber Research Institute of Malaya*, 23 : 286-289.

Lowery, H.H. and Kohman, G.T. (1927). Mechanism of the absorption of water by rubber. *Journal of Physical Chemistry*, **31** : 24-36.

Nair, N.R., Thomas, K.T., Varghese, L. and Mathew, N.M. (1988). Solar-cum-smoke drier for raw sheet rubber. *Indian Journal of Natural Rubber Research*, 1(2) : 13-21.

Nanon, B., Benoit, J.M., Berthomieu, G. and Benet, J.C. (1995). Drying of granules from natural rubber latex. *Journal of Natural Rubber Research*, **10**(4) : 228-241.

Newman, A.B. (1931). The drying of porous solids. *Transactions of American Institute of Chemical Engineers*, 27 : 313-321.

Piddlesden, J.H. (1936). The drying of rubber. *Journal of Rubber Research Institute of Malaya*, 7 : 117-146.

Philpott, M.W. and Walker, A.M. (1955). Improvements in the drying of rubber coagulum. *British Patents Specification*, **726** : 181.

Roudeix, H. (1985). Improvement of natural rubber processing and drying conditions by getting a more controlled structure of latex coagulum. *Proceedings of the International Rubber Conference*, 1985, Kuala Lumpur, Malaysia, pp. 1-10.

Sekhar, B.C. (1958). Aeration of natural rubber latex. 1. Effect of polyamides on the hardness and ageing characteristics of aerated latex rubber. *Rubber Chemistry and Technology*, **31** : 425-440.

Sherwood, T.K. (1931). Application of theoretical diffusion equations to the drying of solids. *Transactions of American Institute of Chemical Engineers*, 27 : 437-435.

Tillekeratne, L.M.K., Nugawela, A., Jayasuriya, S., Weeraman, S. and Siriwardena, T.A. (1995). Utilization of sunlight for drying of rubber. *Journal of Natural Rubber Research*, **10**(2) : 77-81.

Yogaratnam, N., Tillekeratne, L.M.K., Karnika de, Silva, K.G., Siriwardena, s. and Samarappuli, I.N. (1998). Processing of NR and some developments in rubber chemistry and technology in Sri Lanka. *Bulletin of the Rubber Research Institute of Sri Lanka*, **37** : 52-61.