Drying Mechanism of Rubber from the Natural Rubber Latex Vulcanized by Gamma Rays

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Introduction

Radiation vulcanized natural rubber latex process is carried out at room temperature (Machi, 1989). The radiation vulcanized latex remains in the liquid state. This characteristic allows the fabrication of products by dipping process. The drying mechanism of rubber from radiation vulcanized latex was studied In this work.

Methods

Concentrated natural rubber latex containing 5 phr of n-BA and 0.2 phr of KOH was irradiated with gamma rays from the ^{60}Co source at room temperature and the dose was 10 kGy.

The drying tests (Keyy, 1972) were carried out with the rubber films obtained by dipping process on glass plates (20x4.5x0.2 cm). The film thickness was measured with micrometer (0.001x2 mm).

The both drying conditions free and forced convections were carried out into the forced ventilation oven. The both heating conditions were:

a) the air temperature was $50 \pm 2\,^0C$ at atmospheric pressure.

b) the relative media humidity was 75.97 %.

At least 1 h must be heated the oven before beginning the drying test. Automatic temperature control by the thermostatic regulation held the constant temperature at $50\,^0C$. The 14 time ranges were: 0, 5, 10, 20 and 30 minutes completing 144 minutes to free convection and 104 minutes to forced convection. The drying test finished when the equilibrium humidity (X*) became constant.

The influence of the air velocity was studied in the forced convection with the maximum velocity of the forced ventilation oven and it was unknown. The free convection experimental process was performed with the motor forced ventilation of oven turned off. The weight rubber film was 2.2372 g and the media thickness was 0.235 ± 0.034 mm. In the forced convection experimental process the weight rubber film was 2.071 g and the media thickness was 0.201 ± 0.020 mm.

Results and discussion

The curves of humidity versus drying time (Figure 1) show the decrease of the humidity to X* = 0.0021 and X* = 0.0015 for the free and forced convections respectively.

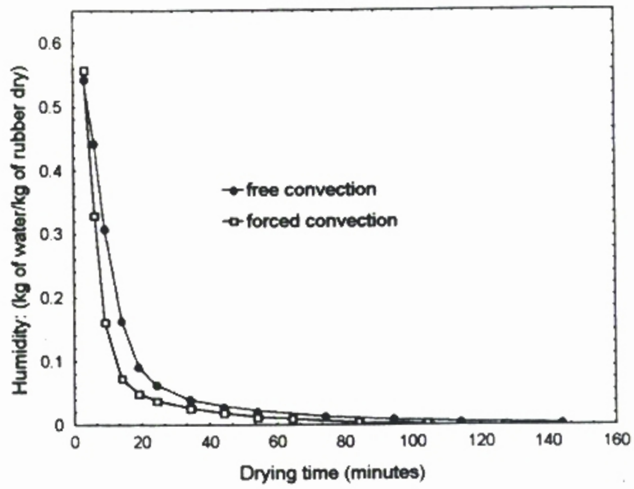

Figure 1 - Humidity versus drying time of rubber films.

The Figure 2 was obtained by mathematical increment humidity data from Figure 1. This Figure shows the relationship between water evaporation rate through rubber ($dx/d\theta$) and the humidity still present in the rubber. It can be observed that the several ranges are similar when we compare both experimental processes however the drying performance were different. The first range AB that could not exist corresponds to induction period where the drying mechanism is not yet stable. The drying velocity is constant up to critical humidity (Xc = 0.161) in the second range BC that corresponds to anti-critical period. After this range occurs a pronounced decrease up to zero humidity values (post-critical period).

Anti-critical period

This period shows that $dx/d\theta$ is not constant in function of the humidity because has low superficial humidity. However this relation is linear and for the forced convection is:

$$dx/d\theta = 0.04305 + 0.0906\,X \qquad (1)$$

and for the free convection is:

$$dx/d\theta = 0.03124 + 0.0211\,X \qquad (2)$$

Replacing X by $X_c = 0.161$ in the equations 1 and 2 it obtains: 0.0576 and 0.0346 $minutes^{-1}$ for forced and free convection, respectively. The anti-critical period time was : 9.01 e 14.18 minutes to forced and free convections respectively.

The drying velocity at the critical point (w_c) can be calculated from the following equation:

$$w_c = \frac{S}{A}\left(-\frac{dX}{d\theta}\right) \qquad (3)$$

For the forced convection $S/A = 2.071/180 = 0.0115$ g/cm^2 and $w_c = 0.0576 \times 0.0115 = 0.000662$ g/(minutes.cm^2) or 0,397 kg/(h.m^2). For the free convection $S/A = 2.237/180 = 0.0124$ g/cm^2 and $w_c = 0.0346 \times 0.0124 = 0.000429$ g/(minutes.cm^2) or 0.257 kg/(h.m^2).

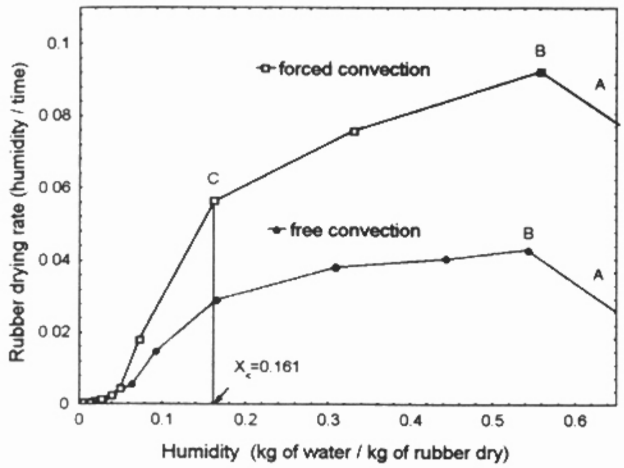

Figure 2 - Rubber humidity evaporation rate.

Post-critical period

The drying laws of these periods are presented in the Figure 3. This Figure represents the relationship between log-humidity and the drying time. In these experimental conditions the post-critical period equation was obtained and it allows to evaluate the post-critical drying period in another conditions.

Both kinds of the convections are almost linear in the first post-critical drying period. The angular coefficient m is calculated by following equation:

$$m = \frac{\Delta \log \dfrac{X - X^*}{X_0 - X^*}}{\Delta \theta} \qquad (4)$$

where X_0 is the initial humidity of this period.

The replacements of the X_0 by $X_c = 0.161$ and X^* by 0.0021 value and m by -0.00462 and - 0.00257 minutes^{-1} for the forced and free convections respectively allow to get the post-critical first period equation that include the first 64 minutes after the drying beginning. These equations are:

$$\theta = -0.004625 \log \frac{X - X^*}{X_0 - X^*} \qquad (5)$$

$$\theta = -0.002574 \log \frac{X - X^*}{X_0 - X^*} \qquad (6)$$

In the equations 5 and 6 θ is the post-critical drying time up to the humidity X measured after the anti-critical period time of the 9.01 and 4.18 minutes for the forced and free convections respectively. Therefore the first post-critical period time will be 64 - 9.01 = 54.99 and 94 - 14.18 = 79.82 minutes to forced and free convections respectively.

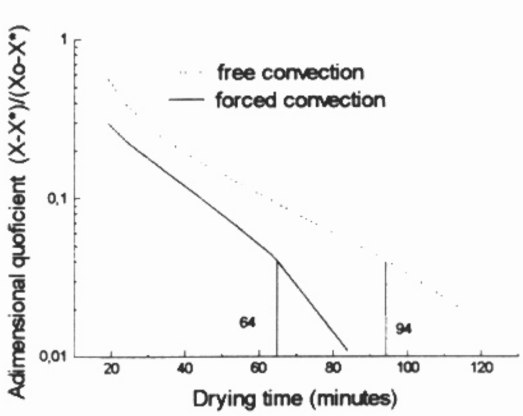

Figure 3 - Drying in the post-critical period.

Conclusions

The evaporation velocity values in the critical point was 0.3976 kg/h.m^2 for forced convection and 0.2583 kg/h.m^2 for free convection. These values indicate that can be removed a bigger quantity of water in the forced convection in the anti-critical period. The rubber critical humidity was 0.161 for both experimental process showing that the air velocity does not influence in the critical humidity values for the thickness films least than 0.2 mm. The drying velocity occurs by water evaporation from the total film surface when the humidity is smaller than the critical humidity.

References

Keyy, B. R. "Drying: Principles and Practice", Mc-graw Hill. (1972).

Machi, S. "Radiation Vulcanization of Natural Rubber Latex". JAERI-M-89-228. (1989).