Poster Presentation

The 7th TSME International Conference on Mechanical Engineering
13-16 December 2016

POS0005

Effect of Drying Conditions on Energy Consumption of Para Rubber Sheet Drying

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Abstract

Under daily different weather conditions particularly in the South of Thailand, raw para rubber sheet was necessary to dry by hot air dryer for avoiding mold problem before storage and shipment. The objective of this research was investigated effect of various drying conditions on drying kinetics, color and energy consumption of raw para rubber sheet during drying. The raw sample with an initial moisture content of 25.0% dry basis (d.b.) was dried by hot air dryer, consisted of electrical 2.0 kW blower and 1.0 kW heater, in a range of temperature and air velocity of 50 - 70ºC and 0.3 - 0.7 m/s, to the final moisture content of 3.0% d.b. The results showed that the time used in drying process related the drying temperature and air velocity; that time was decreased with increasing the drying temperature and air velocity. The drying by hot air temperature of 70ºC and air velocity of 0.7 m/s was the shortest. In the range of drying condition study, dried para rubber sheet had color quality, analyzed by colorimeter in terms of whiteness/blackness (L^*), redness/greenness (a^*), yellowness/blueness (b^*) and Hue angle, following by commercial standard. To dry raw para rubber sheet with the lowest energy consumption, it should be dried by hot air temperature of 70°C and air velocity of 0.7 m/s for 16 hr.

Keywords: Drying, Energy consumption, Para Rubber Sheet

1. Introduction

Para rubber sheet was the product that Thailand has been one of the top exporters of the world [1]. Before transport for distribution, the para rubber sheet was required to reduce the moisture incurred during the production process to the suitable level to avoid the fungal infection. At present there are two moisture reduction methods, that is, sun drying and hot air drying. The advantage of sun drying is that there is no energy cost but the moisture reduction process need a vast space and a number of manpower. Besides, there was fungal infection problem on the surface because the temperature and relative humidity could not be controlled during the moisture reduction process and then the color of the para rubber sheet did not reach the proper standard provided by the Para Rubber Research Institute [2]. Therefore, to produce the medium and large para rubber sheet scale, the drying method with hot air was preferable, particularly in the south of Thailand where the weather had varied every day.

Such drying process was quite complicated with regard to heat and mass transfer which had required energy in the process. In some countries, the energy consumption was related to the drying process had reached 25% of the total domestic production of the country [3-5]. Therefore, the current drying process had required development in efficiency of the production process, quality improvement and reduction of product loss, including eco-friendly production process because such energy consumption was directly related to greenhouse gas production [6-7].

This research was designed to study the drying kinetics of para rubber sheet drying in conjunction with analysis on color quality and energy consumption in the actual drying process. The suitable para rubber sheet production with respect to the standard color quality and the minimum energy consumption would be determined after the test.

2. Materials and methods

2.1 Materials

The raw para rubber sheet size 12.5 x 30 x 0.3 cm and initial moisture content of 25.0±2.0% d.b. obtained from Agriculture, Food and Energy Center, King Mongkut's Institute of Technology Ladkrabang, Prince of Chumphon Campus, Chumphon, Thailand was used in this study.

2.2 Methods

The para rubber sheet dryer consisted of air tube with a diameter of 20 cm, drying chamber with sizing of 60 x 70 x 100 cm (width x length x height), 2 kW blower and 1 kW heater as shown in Figure 1. The samples were dried by hot air in the range of temperatures and velocities of 50 - 70°C and 0.3 - 0.7 m/s until the final moisture content reduced to 3.0±1.0% d.b. The drying kinetics, energy consumption and change of sample color at various conditions were analyzed during drying process. The color parameters expressed with L^*, a^*, b^* and Hue angle were three duplicate analyzed by colorimeter (Minolta, model CR400, Tokyo, Japan). The dried para rubber sheet by sun drying for 14 days with the highest quality of commercial market was employed to sample as standard quality color. As mentioned color, the values of L^*, a^*, b^* and Hue angle were 48.81, 2.97, 26.04 and 83.49, respectively. For energy consumption of dryer, it was measured by meter specifications (Mitsubishi, model MF-33E, Bangkok, Thailand).

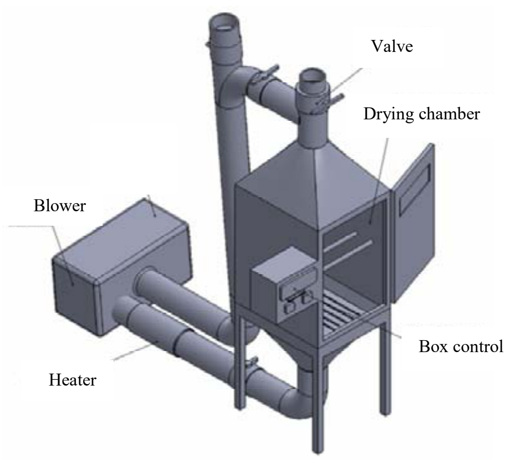


Fig. 1 Para rubber sheet dryer

3. Results and discussion

3.1 Drying kinetics

Figure 2 shows change of moisture and temperature of the para rubber sheet during the hot-air drying process at temperature of 50, 60 and 70°C and the velocity of 0.3 m/s. For the first four hours of the drying process, the moisture of the para rubber sheet at all temperatures tended to decrease rapidly. Then, the drying rate seemed to relate with the drying temperature; it increased with increasing of drying temperature. The drying temperature at 70°C would result in the shortest drying period at 32 hours. For para rubber sheet temperature, it increased quickly during the initial period of the drying process. Such increase was directly related to the temperature employed in the heating process as shown in Figure 2b. Figures 3a and 3b illustrate the changes in moisture and temperature of the para rubber sheet at temperature of 70°C and velocity of 0.3, 0.5 and 0.7 m/s. During the initial state of the drying process, particularly the first four hours, when the velocity was 0.7 m/s, the drying rate of moisture was faster than that of rate at the velocity of 0.3 and 0.5 m/s. After that, the moisture of all samples tended to decrease in accordance with the drying time. At the temperature of 70°C, the periods employed to reduce the moisture of the para rubber sheet to the required level were 32, 24 and 16 hours for the velocity of 0.3, 0.5 and 0.7 m/s, respectively. For the temperature of the para rubber sheet during the drying process at different velocities, it was found that at the same drying temperature the increase in the velocity did not affect the change in the temperature of the para rubber sheet.

During the initial state of the drying process, the surface of the para rubber sheet was still highly moisture. Subsequently, the drying rate of this state was dependent on the difference between the vapor pressure at the surface of the rubber sheet and the hot air [8]. Therefore from the graph of the change in moisture, the increase in velocity would enhance the drying rate at the same drying temperature. The moisture of the rubber sheet had decreased rapidly when the velocity was 0.7 m/s for the first four hours of the drying. After this state of drying, the drying rate would be controlled by the effective moisture diffusivity from inside to the surface of the rubber sheet to release the moisture which such diffusivity value was varied directly in accordance with the rubber sheet temperature. Therefore, at the same velocity employed in the drying process, the drying temperature of 70°C resulted in the shortest drying time [9, 10].

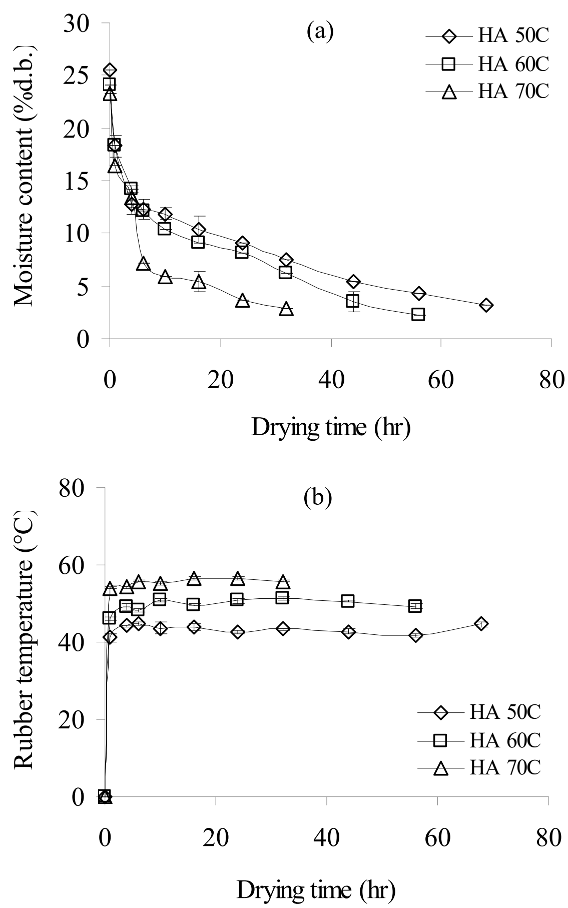


Fig. 2 Change of moisture content (a) and temperature (b) of sample during drying by various hot air temperatures and velocity of 0.3m/s

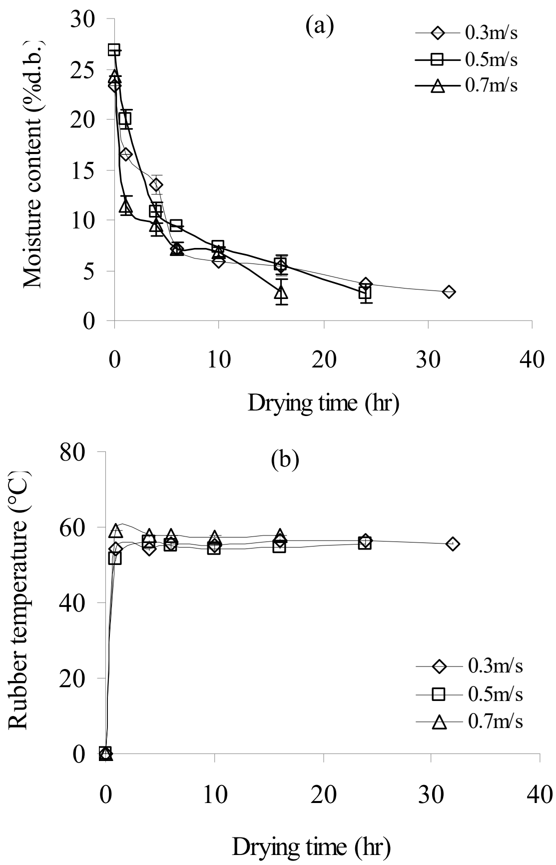


Fig. 3 Change of moisture content (a) and temperature (b) of sample during drying by various hot air velocities and temperature of 70°C

3.2 Color analysis

Table 1 shows the changes in color value of raw and dried para rubber sheet at different conditions. The raw para rubber sheet had L^*, a^*, b^* and Hue angle initially of 93.05, 1.85, 10.67 and 99.84, respectively. After the para rubber sheet had been through the drying process at different temperatures and velocities, L^* and b^*, which indicate the values of whiteness or blackness and yellowness or blueness had obviously changed while the values of a^* and Hue had not changed much from that of the raw para rubber sheet. The decrease in L^* and the increase in b^* were resulted from non-enzymatic maillard reaction during the drying process, resulting in the color of the para rubber sheet had turned dark yellow [11, 12].

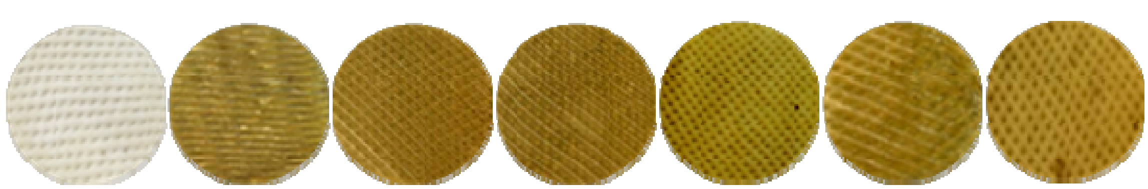
Nevertheless, when the color of the dried para rubber sheet by hot air was compared with the standard quality sample reduced the moisture through sun drying for 14 days, it was found that the dried para rubber sheet by hot air which had been through the drying process in the study had the color within the range of standard quality because the value of L^* was not less than 48.81 and the value of b^* was not greater than 26.04. Such outcome correlated with the comparison of the dried para rubber sheet samples at final moisture content as shown in Figure 4.

3.3 Energy consumption analysis

Figure 5 shows the energy consumption of the drying process of the para rubber sheet at different temperatures and velocities. At the velocity of 0.3 m/s, the electrical energy employed in the drying process at temperature of 50, 60 and 70oC was 181, 146 and 95

Table 1 Change of raw and dried sample color treated by various drying conditions

Drying conditions		L^*	a^*	b^*	*Hue*
Velocity (m/s)	Temperature (°C)				
0.3	50	50.88 ± 1.32	2.57 ± 0.59	25.28 ± 0.66	85.30 ± 1.11
	60	49.12 ± 4.09	4.09 ± 1.26	19.46 ± 1.89	82.97 ± 0.66
	70	52.07 ± 4.38	0.27 ± 1.03	19.31 ± 1.47	83.25 ± 0.42
0.5	50	57.28 ± 0.92	0.27 ± 0.23	23.09 ± 0.56	87.09 ± 0.12
	60	49.97 ± 2.71	0.99 ± 0.14	16.39 ± 0.76	86.17 ± 1.53
	70	58.98 ± 3.13	0.28 ± 0.75	21.55 ± 2.03	84.45 ± 0.95
0.7	50	51.34 ± 0.79	2.07 ± 0.26	22.83 ± 0.57	84.83 ± 0.38
	60	57.19 ± 1.02	0.58 ± 0.44	25.52 ± 0.16	88.50 ± 0.89
	70	58.27 ± 0.69	1.15 ± 0.44	24.04 ± 0.02	86.69 ± 1.23
Sun drying		48.81 ± 0.54	2.97 ± 0.16	26.04 ± 1.50	83.49 ± 0.50
Raw para rubber sheet		93.05 ± 0.32	1.85 ± 0.12	10.67 ± 0.22	99.84 ± 0.46



Raw Sun drying 50°C&0.3m/s 60°C&0.3m/s 70°C&0.3m/s 70°C&0.5m/s 70°C&0.7m/s

Fig. 4 Raw and dried para rubber sheet samples at final moisture content kWh, respectively. The energy power employed in the blower was higher than that employed in the heater for 5-11%. When the comparison on energy consumption in the drying process was made at the temperature of 50 and 60°C, it was found that the increase in the velocity had resulted in an increase in the energy consumption, particularly by the blower. Such result was in contrast with the drying process at the temperature of 70°C since the increase in the velocity had resulted in a decrease in the energy consumption because the increase in the velocity had increased the drying rate only during the first four hours to remove the moisture on the surface of the para rubber sheet. Then, the drying rate would be dependent on the temperature employed in the drying process to diffuse the inner moisture to the surface of the para rubber sheet as mentioned in the drying kinetic result. Therefore, increase in the velocity when the low temperature was employed in the drying process was not proper for the energy consumption [13 - 16]. The result from the graph seemed to illustrate that the temperature of 70°C and the velocity of 0.7 m/s were the appropriate condition for heat and mass transfer during the drying process because the energy consumption value was the lowest.

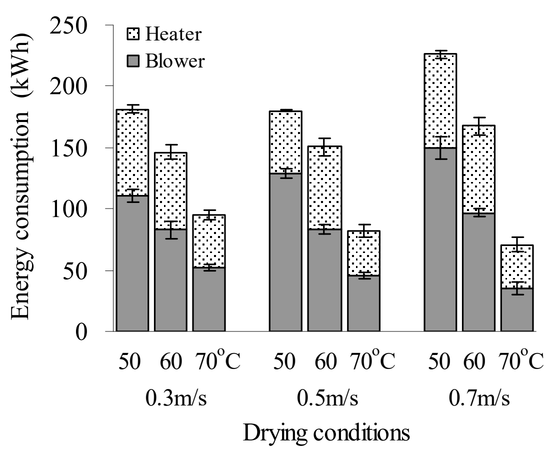


Fig. 5 Energy consumption of para rubber sheet drying

4. Conclusions

The increase of drying temperature and velocity directly affected the drying rate; the rate increased with increasing of both factors. The hot air drying process within the scope of study could produce the para rubber sheet with standard quality color. The suitable drying condition to dry para rubber sheet with the lowest energy was drying temperature of 70°C and velocity of 0.7m/s.

5. Acknowledgement

The authors thanks to Agriculture, Food and Energy Center, King Mongkut's Institute of Technology Ladkrabang, Prince of Chumphon Campus, Chumphon, Thailand for para rubber sheet sample and also thanks to King Mongkut's Institute of Technology Ladkrabang Research Fund for financial support.

6. References

[1] Rubber Research Institute of Thailand, Department of Agriculture, Thailand (2015). Thai Rubber Statistic, URL:http://www.rubberthai.com/statistic/stat_index.htm, accessed on 29/08/2016

[2] Ninchuewong, T., Ekphon, A., Supawan Tirawanichakul, S. and Tirawanichakul, Y. (2012). Drying of air dried sheet rubber using hot air dryer and solar dryer for small entrepreneurs and small rubber cooperatives, *Burapha Science Journal*, Vol. 17(2), pp. 50 – 59.

[3] Mujumdar, A.S. and Huang, L-X. (2007). Global R&D needs in drying, *Drying Technology*, Vol.25, pp.647 – 58.

[4] Kemp, I.C. (2011). Fundamentals of energy analysis of dryers. In: Tsotsas E, Mujumdar A.S, editors. Modified Drying Technology – Energy Savings, Weinheim: Wiley-VCH Verlag GmbH; p. 1 – 46.

[5] Defraeye, T. (2014). Advanced computational modelling for drying processes – A review, *Applied Energy*, Vol. 131, pp. 323 – 344.

[6] Gong, Z.X. and Mujumdar, A.S. (2008). Software for design and analysis of drying systems, *Drying Technology*, Vol.26, pp.884 – 94.

[7] van Boekel, M.A.J.S. (2008). Kinetic modeling of food quality: a critical review, *Comprehensive reviews in food science and food safety*, Vol.7, pp.144–58.

[8] Defraeye, T., Blocken, B. and Carmeliet, J. (2012). Analysis of convective heat and mass transfer coefficients for convective drying of a porous flat plate by conjugate modeling, *International Journal of Heat and Mass Transfer*, Vol.55, pp.112 – 24.

[9] Thuwapanichayanan, R., Prachayawarakorn, S., Kunwisawa, J. and Soponronnarit, S. (2011). Determination of effective moisture diffusivity and assessment of quality attributes of banana slices during drying, *LWT - Food Science and Technology*, Vol.44, pp. 1502 – 1510.

[10] Si, X., Chen, Q., Bi, J., Yi, J., Zhou, L. and Wu, X. (2016). Infrared radiation and microwave vacuum combined drying kinetics and quality of raspberry, *Journal of Food Process Engineering*, Vol. 39(4), August, pp. 377 – 390.

[11] Soponronnarit, S., SrisubatiI, N. and Yoovidhya, T. (1998). Effect of temperature and relative humidity on yellowing rate of paddy, *Journal of Stored Products and Research*, Vol. 34, pp. 323 – 330.

[12] Dai, L., Kang, G., Li, Y., Nie, Z., Duan, C. and Zeng, R. (2013). In-depth proteome analysis of the rubber particle of Hevea brasiliensis (para rubber tree), *Plant Molecular Biology*, Vol. 82, pp. 155 – 168.

[13] Jittanit, W., Saeteaw, N. and Charoenchaisri, A. (2010). Industrial paddy drying and energy saving options, *Journal of Stored Products Research*, Vol. 46(4), pp. 209 – 213.

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[14] Perré, P., Rémond, R., Colin, J., Mougel, E. and Almeida, G. (2012). Energy consumption in the convective drying of timber analyzed by a multiscale computational model, *Drying Technology*, Vol.30, pp. 1136 – 46.

[15] Aghbashlo, M., Mobli. H., Rafiee, S. and Madadlou, A. (2013). A review on exergy analysis of drying processes and systems, *Renewable and Sustainable Energy Reviews*, Vol.22, pp.1 – 22.

[16] Ibrahim, M.N., Tajaddodi. Talab, K., Spotar, S., Muhammad, K. and Talib, R.A. (2013). Effect of airflow reversal in fixed-bed drying of rough rice on head rice yield and drying performance, *American Society of Agriculture and Biological Engineering*, Vol. 56(4), pp. 1485 – 1493.