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DRYING KINETICS OF THE TESTA AND COTYLEDON LAYERS OF COCOA BEANS

Hii Ching Lik and Law Chung Lim

Department of Chemical & Environmental Engineering, University of Nottingham, Malaysia Campus, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia
Email: Ching-Lik.Hii2@nottingham.edu.my

ABSTRACT

Studies were carried out to investigate the drying kinetics of the individual layers of cocoa beans namely the testa and cotyledon. The cocoa beans were dried using dehumidified air at 28.2°C, 40.4°C and 56°C in thin layer inside a heat pump dryer. Moisture contents of the bean, testa and cotyledon were determined throughout drying. Reduction in moisture content was relatively fast at the testa as compared to the cotyledon in the initial two hours of drying. Subsequent drying showed a crossover where the moisture content of the testa overtook the cotyledon. From this stage onwards further drying would not reduce the testa moisture content significantly as compared to the cotyledon. Only falling rates were observed throughout drying and the drying rates of the testa were much greater than the cotyledon due to the higher initial drop in moisture content. It was observed that final moisture content of the testa was higher as compared to the inner cotyledon at the end of drying. This showed that moisture migrated from the lower moisture content cotyledon to the higher moisture content testa during drying. Such transfer mechanism seems contradict but the mass transfer potential concept as postulated by Luikov explains that the transfer is due to moisture potential difference instead of moisture content difference. Such transfer mechanism is explainable especially for a double body system that contains different initial moisture content at both sections.

Keywords: *cocoa, drying, heat pump, Luikov, mass transfer*

INTRODUCTION

Upon harvesting, cocoa beans (Theobroma cacao L.) are fermented and dried during processing. Fermentation is usually carried out for 5–7 days while drying is carried out thereafter to complete the browning process [1,2]. In general, fresh cocoa beans consist of three layers i.e. pulp, testa and cotyledon. However, only two distinct layers, namely the outer testa and the inner cotyledon, play a major role in affecting the drying kinetics. The moisture contents of these layers are typically about 300% and 50% (dry basis), respectively. The testa acts as a protection to the cotyledon to prevent spoilage by insects and pests during storage.

Many studies had tried to simulate the drying characteristics of the testa and cotyledon layers by theoretical means [3,4]. Páramo et al. [5] reported the kinetics of water and acids in cocoa beans with and without shell. However, none of these studies had reported the drying kinetics of the individual layer of cocoa bean with both the testa and cotyledon intact throughout the drying process.

Therefore, studies were carried out to investigate the drying kinetics of the testa and cotyledon with both layers intact during drying. This is necessary in order to better understand the drying characteristics of these layers during cocoa drying. Heat pump dryer was used throughout the drying studies.

MATERIALS AND METHODS

Samples

About 700 g fermented cocoa beans were dried thinly on two meshed surface (0.3 m 0.3 m each) inside the drying chamber. Trials were carried out based on the conditions in Table 1. Moisture content (X_i) was determined hourly for the bean, testa and cotyledon by using Eq. (1). Random samples (30 beans) were obtained hourly and the testa was peeled using a penknife from the cotyledon. The weights of the testa and cotyledon were then weighed separately in a digital balance. Dry solid weight was then determined by drying the hourly collected samples (testa and cotyledon) in a convective oven at 105°C for at least 24 hours. Drying was terminated when the beans reached equilibrium moisture content (EMC).

$$X_i = \frac{M_i - M_{ds}}{M_{ds}} \times 100 \quad (1)$$

Where Mi = sample weight (g), ds = dry solid content.

Table 1 Operating conditions used in the heat pump dryer

Label	V_{air} (ms^{-1})	T_{air} (°C)	RH_{air} (%)
H5	4.6±0.5	56.0±2.0	14.6±1.0
H4	4.6±0.5	40.4±2.0	18.1±1.0
H2	4.6±0.5	28.2±2.0	26.7±1.0

*The readings are expressed as means ± SD (n=3)

Heat pump dryer

The heat pump dryer was fabricated and supplied locally by ILab Sdn. Bhd. (Selangor, Malaysia). Fig. 1 shows the schematic diagram of the heat pump dryer. Overall built-up dimension of the dryer is 2.3 m x 1 m x 2.1 m (L x W x H) and comes with two drying chambers measured 0.33 m x 0.33 m x 1 m each.

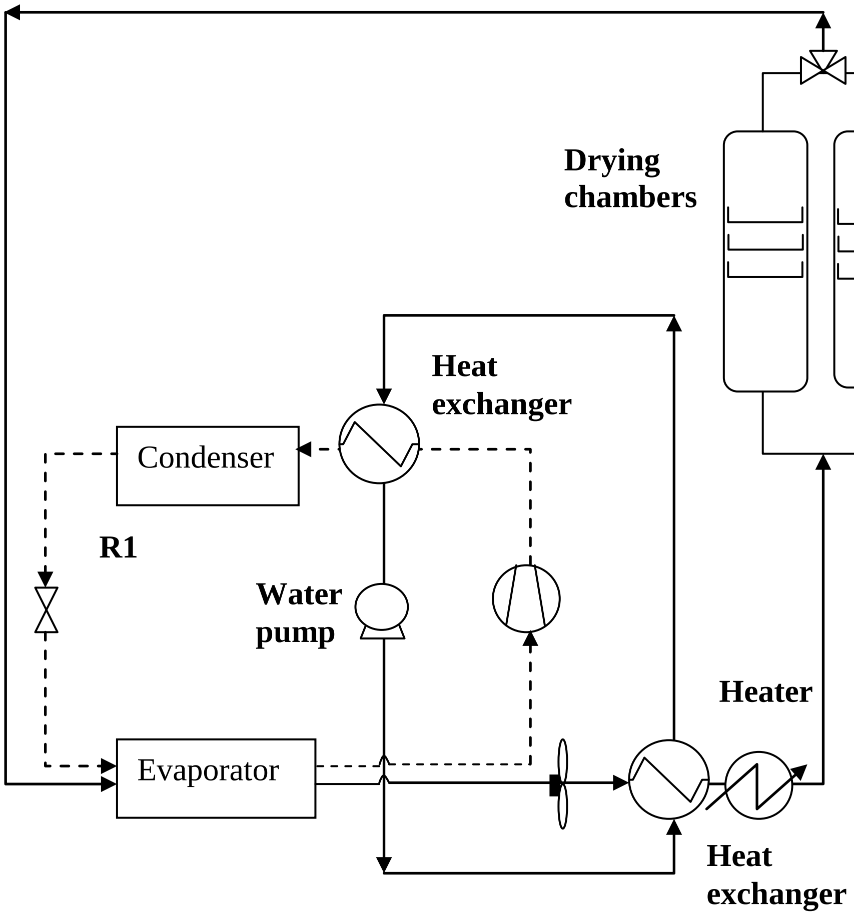


Fig.1: Schematic of the heat pump dryer

Drying rates

The drying rates were calculated by approximation of the derivatives to finite differences [6] based on the following equations (2-4).

For $t = t_0$ (initial time),

$$\frac{dX}{dt} = \frac{X_1 - X_0}{t_1 - t_0} \tag{2}$$

For $t = t_i$ (i = 1,…., N-1),

$$\frac{dX}{dt} = \frac{X_{i+1} - X_{i-1}}{t_{i+1} - t_{i-1}} \tag{3}$$

For $t = t_N$ (final time),

$$\frac{dX}{dt} = \frac{X_N - X_{N-1}}{t_N - t_{N-1}} \tag{4}$$

RESULTS AND DISCUSSIONS

Fig. 2 shows the moisture content profiles for the cotyledon and testa at various drying conditions. Initial moisture contents were determined at 0.67 – 0.77 g H_2O g^{-1} dry solid, 2.3 – 3.3 g H_2O g^{-1} dry solid and 0.96 – 1.01 g H_2O g^{-1} dry solid for the cotyledon, testa and whole bean, respectively. Moisture removal from the testa is faster which is due to the higher surface moisture exposed to the convective air at the testa layer. Diffusion of moisture from the cotyledon to the outer surface is gradually restricted thereafter as the testa starts to dry up. Equilibrium moisture contents were found ranging from 0.06 g H_2O g^{-1} dry solid to 0.09 g H_2O g^{-1} dry solid, 0.1 g H_2O g^{-1} dry solid to 0.19 g H_2O g^{-1} dry solid and 0.07 g H_2O g^{-1} dry solid to 0.09 g H_2O g^{-1} dry solid, for the cotyledon, testa and whole bean, respectively. The testa layer reaches EMC much earlier due to the immediate contact with the convective air current.

A cross over between the moisture content of the cotyledon and the testa can be observed and this occurs at cotyledon moisture content of 0.12 – 0.20 g H2O g^{-1} dry solid. Further drying beyond this level will not reduce the moisture content of the testa significantly as compared to the cotyledon. The final moisture content of the testa was actually higher than the cotyledon. This shows that resistance to mass transfer is contributed by the testa and there is a reduced diffusion rate once the moisture reaches this layer. This is supported by the simulation works carried out by Daud et al. [3,7] where the moisture diffusivity values estimated for the testa layer is 10 – 14 times smaller than the cotyledon layer in the order of magnitude of 10^{-11} m^2s^{-1}.

Therefore, the testa layer serves as a transit zone where moisture accumulated at this layer and gradually removed from the testa surface by convection. Such mechanism might seem contradict to the usual understanding of mass transfer due to moisture content gradient but this can be explained based on the concept of mass transfer potential [8]. In a system of bodies with discontinuity in moisture content at the interface, the driving mechanism is due to the difference in mass transfer potential between the two bodies. However, mass transfer potential data for food materials are not readily available in published literatures to date but this can be interpreted in the form of moisture ratio (equation 5) as reported by several authors [9-11]. By using this concept the initial mass transfer potential (moisture ratio) are therefore equal (MR = 1) in both layers prior to drying. By taking the moisture ratio curve of HP5 as an example (Fig. 3), it can be seen that the moisture potential (moisture ratio) of the testa is much lower than the cotyledon during drying and this provides the main driving force of mass transfer across the layers.

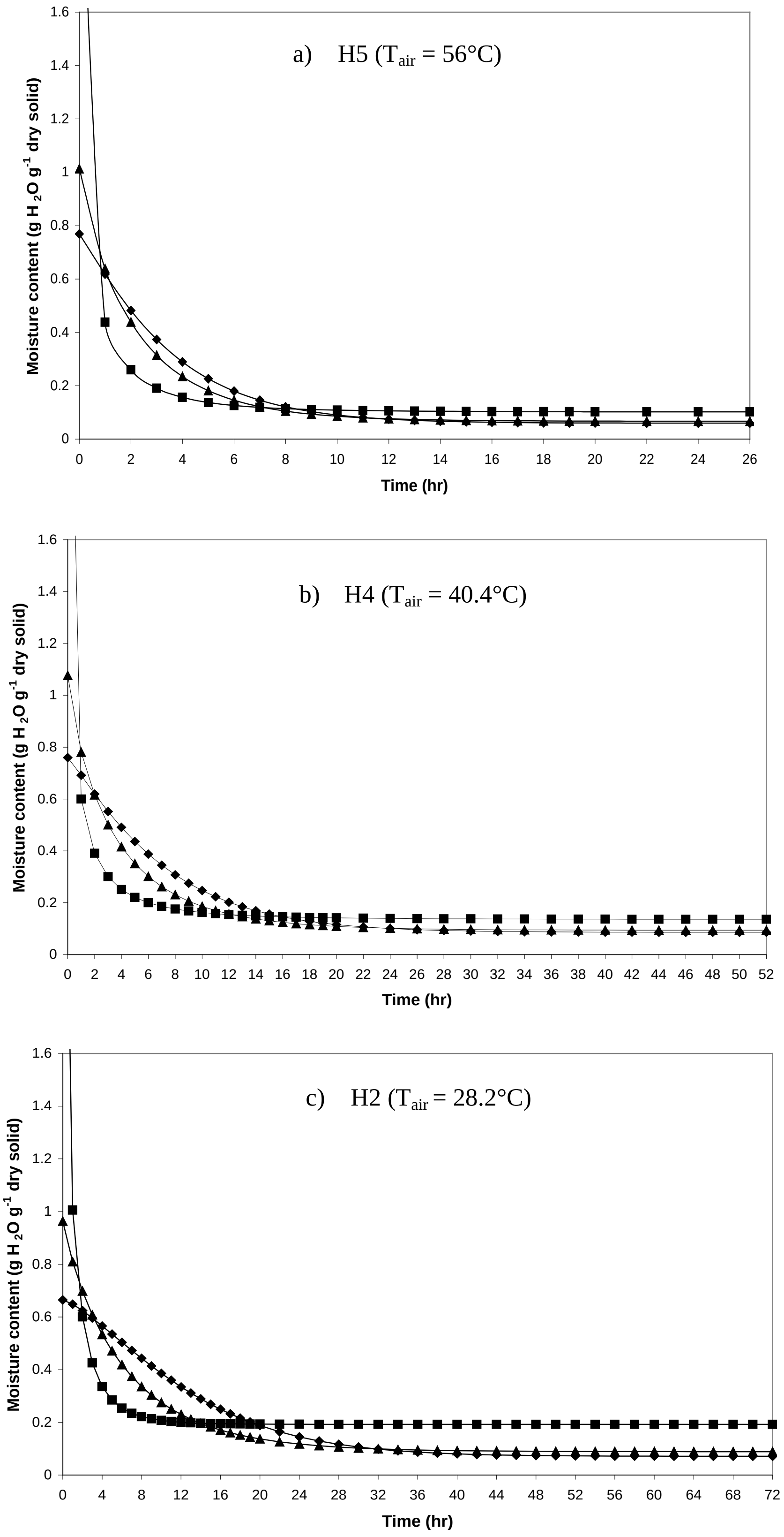


Fig. 2: Drying curves of testa (■), cotyledon (♦) and bean (▲)

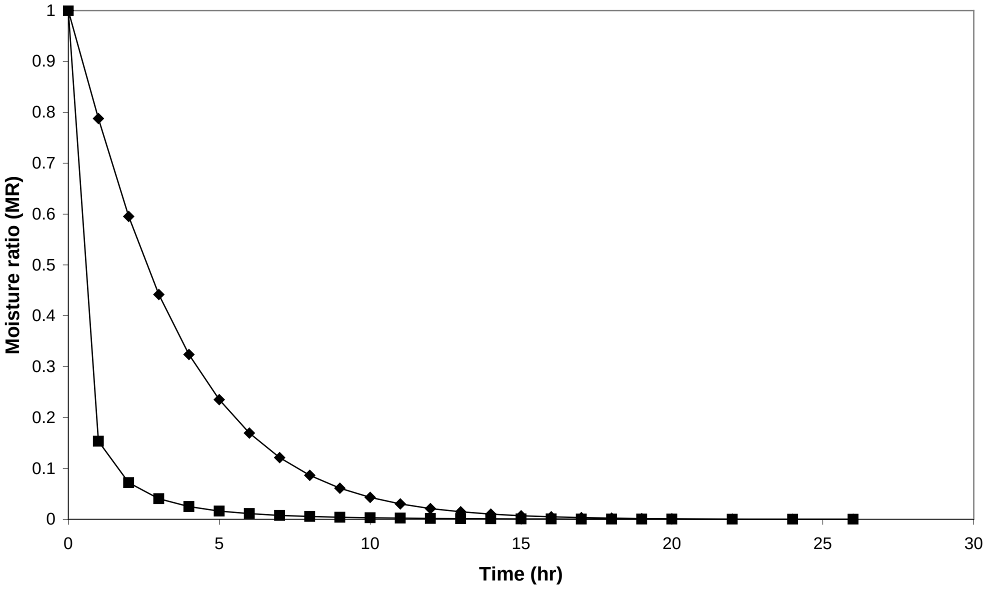
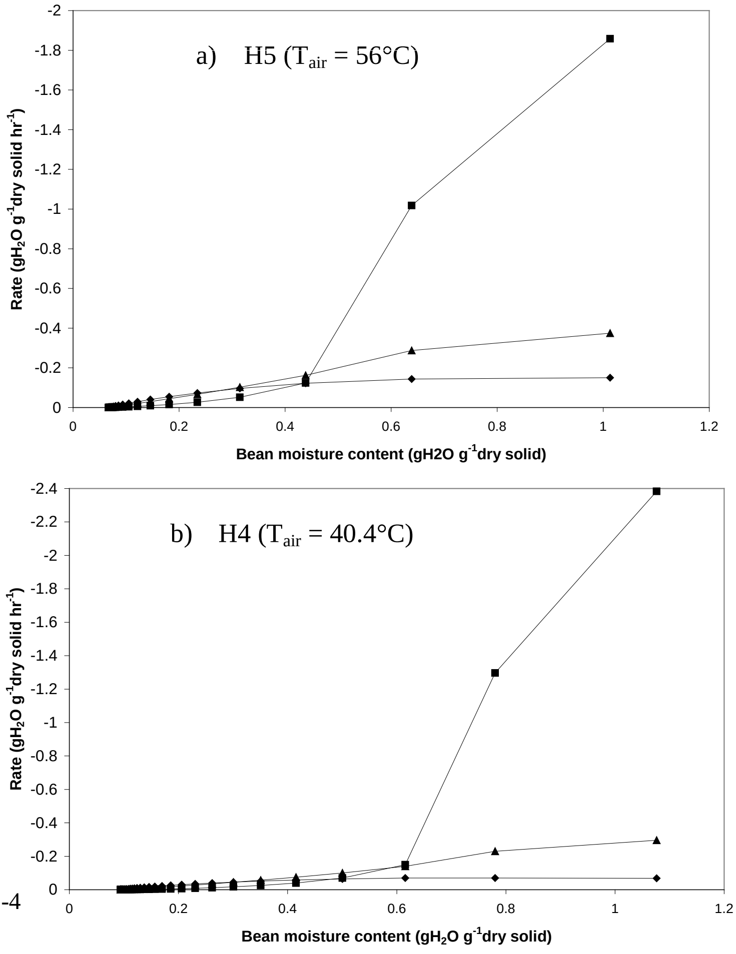


Fig. 3: Moisture ratio curves for testa (■) and cotyledon (♦) in drying trial H5

Moisture ratio:

$$MR = \frac{X_i - X_E}{X_o - X_E} \tag{5}$$

Fig. 4 shows that initial drying rates were estimated ranging from 0.016 g H_2O g^{-1} dry solid hr^{-1} to 0.15 g H_2O g^{-1} dry solid hr^{-1}, 1.85 g H_2O g^{-1} dry solid hr^{-1} to 2.38 g H_2O g^{-1} dry solid hr^{-1} and 0.15 g H_2O g^{-1} dry solid hr^{-1} to 0.37 g H_2O g^{-1} dry solid hr^{-1}, for the cotyledon, testa and whole bean, respectively.



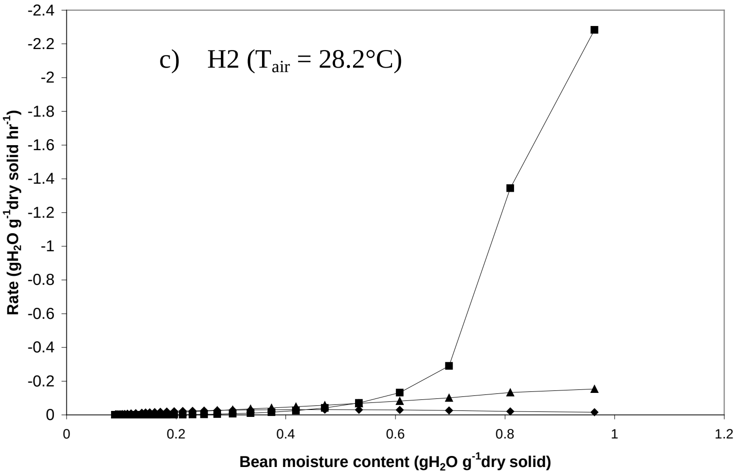


Fig. 4:Drying rates of testa (■), cotyledon (♦) and bean (▲)

The higher rates of the testa were due to rapid drop of the surface moisture content. It can be seen that drying rates of the beans were found contributed mostly by the testa especially in the first two hours of drying. The entire drying rates curve showed the typical falling rates period.

CONCLUSIONS

Studies showed that the cotyledon and testa behaved differently based on the drying kinetics of the individual section. There was a crossover where the testa moisture content was higher than the cotyledon. Final moisture content of the testa was also higher than the cotyledon at the end of drying. This can be explained by Luikov’s mass transfer potential concept where migration of moisture is induced by mass transfer potential difference instead of moisture content difference between the cotyledon and testa. In this study it was found that the mass transfer potential for testa is always lower than the cotyledon based on the moisture ratios. This provides the driving force for mass transfer across these layers.

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