稻穀間歇乾燥之再探討

Further Investigation on Intermittent Drying of Paddy Rice

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主持人：陳貽倫　國立台灣大學農業機械工程學系

一、中文摘要

本研究主要是在 108 個乾燥處理條件下，經由所獲得的薄層稻穀乾燥數據，利用迴歸技術建立出四種薄層乾燥公式，公式中包含四項乾燥參數，即：熱風溫度、絕對濕度、乾燥時間和均化時間，並反應其影響程度。熱風溫度範圍 35 至 65℃，絕對濕度範圍 10 至 26g/kg, 乾燥時間範圍 5 至 15 分鐘，均化時間範圍 40 至 120 分鐘。

關鍵詞：薄層公式、均化、間歇乾燥

ABSTRACT

This article presents thin layer drying data for rough rice from 108 treatments. Based on these data, four thin layer equations are derived by regression analysis. The proposed equations include and reflect the effects of drying air temperature, drying air absolute humidity, drying time interval and tempering time interval. Drying air temperature varies from 35 to 65 ℃, drying air absolute humidity from 10 to 26 g/kg, drying time interval from 5 to 15 minutes and tempering time interval from 40 to 120 minutes.

KEYWORDS: thin layer equations, tempering, intermittent drying

二、緣由與目的

Batch re-circulating rice dryers, in which the grain is dried in an intermittent pattern, prevail in rice-producing Asian countries. The grain is initially dried for approximately 5 to 15 minutes by passing through the drying zone of the dryer. The grain then proceeds to the tempering zone for tempering for around 40 to 120 minutes. The drying-and-tempering cycle is repeated as the grain re-circulates in the dryer until the grain reaches the desired moisture content. Full tempering requires approximately 4 to 6 hours and, occasionally, even longer. The rice is usually not fully-tempered upon arrival to the drying zone for the next-pass drying in the re-circulating dryer. The extent of tempering of the grain depends on both the time interval of drying phase and tempering phase. Notably, the extent of tempering heavily influences the grain's drying rate. If the grain is not fully-tempered, applying the existed thin layer equations would yield some inaccuracies.

Two basic theoretical or semi-theoretical models may simulate thin layer drying of grains (Newman, 1931; Lewis, 1921). Thereafter, many other models were proposed: empirical, theoretical or semi-theoretical ones (Page, 1949; Thompson et al, 1968; Henderson, 1974; Agrawal et al, 1977; Wang et al, 1978; Sharaff-Eldeen et al, 1979; Sharma et al, 1982; Chen, 1995). To our knowledge, both tempering time interval and drying time interval effects as variables in thin layer drying models of rough rice have never been studied. Therefore, this work attempts to determine the relationship between the drying constants and drying air temperature, drying air absolute humidity, rice drying time interval and rice tempering time interval for thin layer drying of rough rice, and to propose thin layer equations applicable to intermittent drying of rough rice.

三、材料與方法

Rice sample

The rice variety used in this study is a common medium grain variety, grown in central Taiwan in 1996. The initial moisture content was around 35% dry basis.

Experimental design and procedure

Rough rice lots of 50g spread on the bottom of drying sieves of 15.6m inside diameter were dried on a sample dryer, using an intermittent drying pattern. The experiment consisted of 108 combinations of drying parameters—three levels of drying air absolute humidity, four levels of drying air temperature, three levels of rice tempering time, and three levels of rice drying time. Each treatment was performed in triplicate. When the drying time expired at each drying interval, the rice sample of each unit cell was poured in sealed glass bottles. Before the tempering time expired, each sample was weighed and recorded. Finally, the sample was unloaded from the bottles to the original drying cell and the drying/tempering cycle was repeated.

Mathematical models

Four thin layer drying models--single term, Page's(1949) , quadratic(Thompson, 1968) and two term are considered herein to fit the obtained data through the experiment.

四、結果與討論

108 experiments, each in triplicate form were performed. Table I summarizes the linear and nonlinear regression analysis results. The coefficients of determination R^2 in Table I are high, and strong correlations are seen in each model. Figure 1 illustrates two of the 324 sets of experimental drying data along with predicted drying curves by the four thin layer models under different drying conditions as indicated. These curves reveal that the estimated moisture content does not equal the experimental moisture content in the single term model when accumulated drying time equals zero. The drying constant A of single term model under these two drying conditions is 0.95 and 0.91, respectively. Therefore, the single term diffusion model does not correlate well with the experimental data during the initial drying period. A longer drying time interval and shorter tempering time interval result in lower the drying rate under a constant drying temperature and humidity.

五、計畫成果自評

These equations can be used to predict the drying behavior of rough rice, if they are applied within the drying temperature, drying absolute humidity, tempering time interval and drying time interval ranges. In the range of tempering time interval from 40 to 120 minutes and drying time interval from 5 to 15 minutes, a shorter drying time interval and a longer tempering time interval are favorable in re-circulating type rice dryer. In addition, a paper about this research has been published in “Drying technology”- a renown journal in this area. And, another will be presented in a related journal.

六、結論

Based on the drying data from 108 treatments of different drying conditions, which are different combinations of four drying parameters, namely, drying air temperature, drying air absolute humidity, drying time interval and tempering time interval. This work experimentally determines thin layer drying equations for medium grain rough rice. Four thin layer drying models have been derived by regression analysis. Among these models, the single term diffusion model appears not to be an adequate model for rice drying at the beginning drying period. The other models can be chosen as the suitable thin layer equations for deep-bed re-circulating rice drying studies depending on specific drying purpose.

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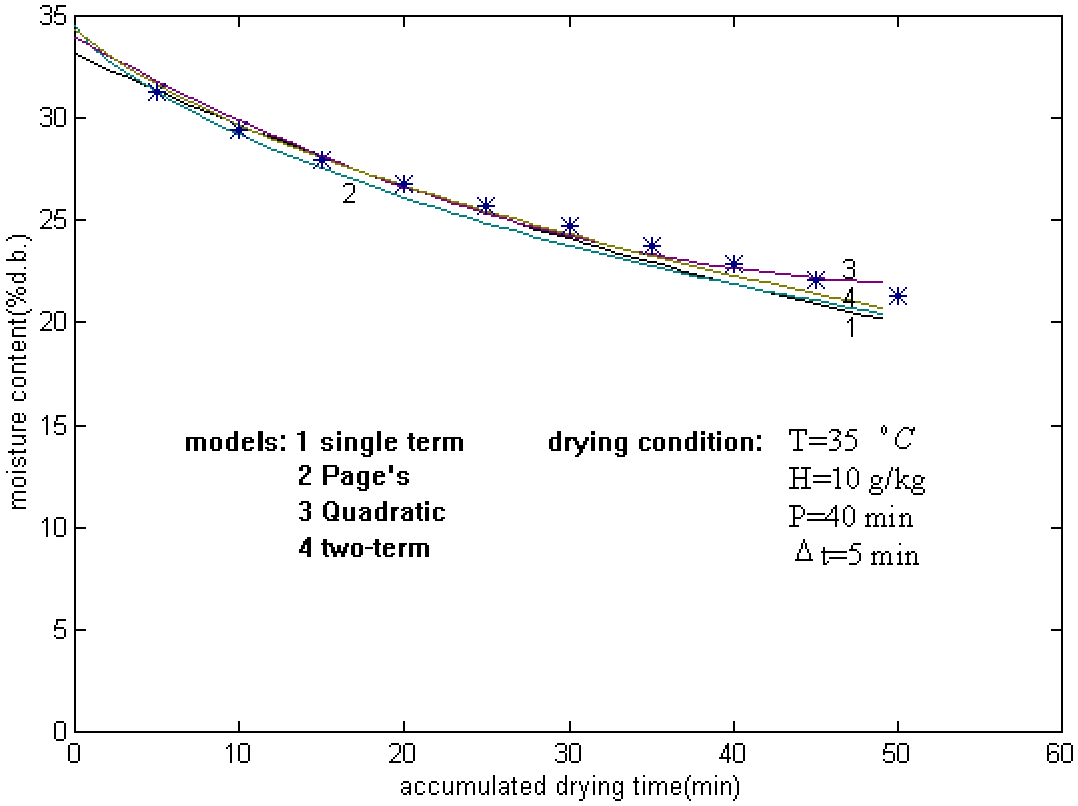

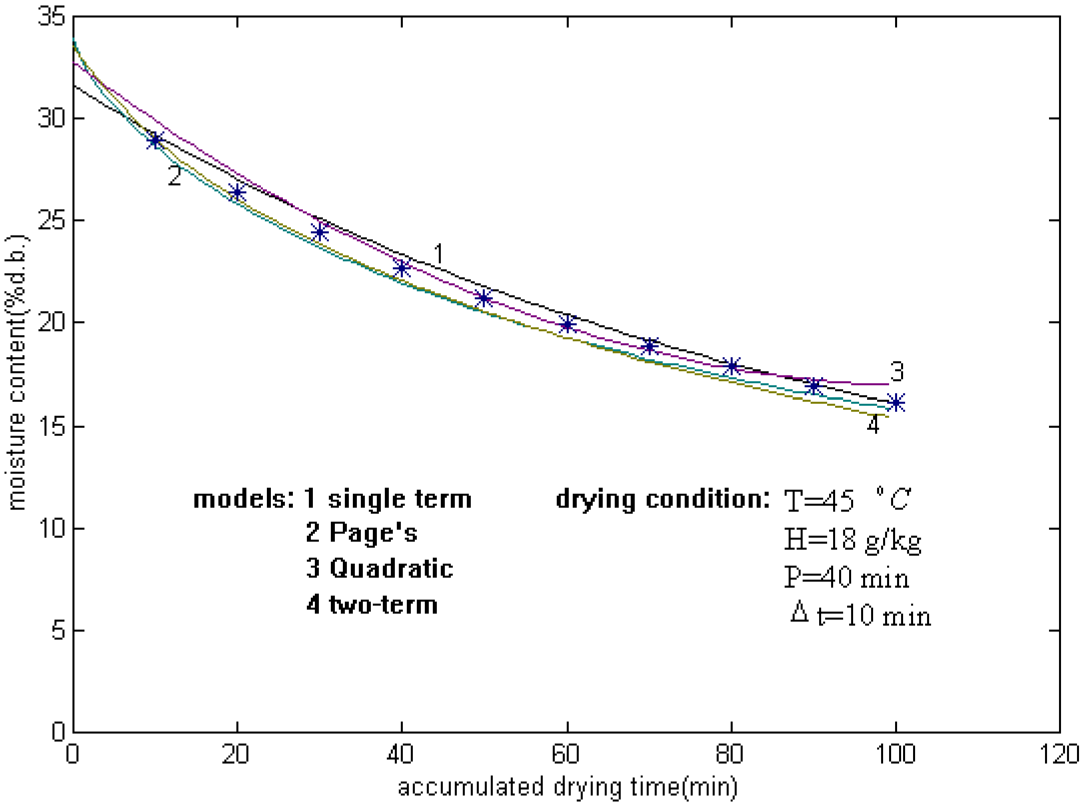

Fig. 1. Two sets of experimental and predicted drying curves. (True lines: regression models; '*': experimental data; T: ℃; H: g/kg; P: Tempering time interval(min), Δt: drying time interval(min) **;** black:"1", green:"2", red:"3", gray:"4")

Table f

Results of Regression Analysis for Different Models[a]

Models	Equations
single term	$MR = Ae^{-kt}$ $A = \exp(-0.15254 - 0.00874H + 0.008449T - 0.0002P +$ $0.00321\Delta t + 0.000213H^2 - 0.000089T^2 + 0.000164\Delta t^2 +$ $0.0000275HP + 0.0000888H\Delta t - 0.00029T\Delta t,\ R^2 = 0.92$ $k = 0.01574 - 0.000478H + 0.00031T + 0.000027P - 0.001957\Delta t$ $-0.0000047H^2 + 0.000079\Delta t^2 + 0.0000092HT + 0.000013H\Delta t -$ $0.0000174T\Delta t,\ R^2 = 0.97$
Page's	$MR = e^{-xt^y}$ $x = 0.008121 + 0.000914T + 0.001398H - 0.00005H^2 - 0.00011P$ $-0.00107\Delta t,\ R^2 = 0.89$ $y = 0.884731 - 0.00078T - 0.0085H + 0.000317H^2 + 0.001132P$ $-0.01999\Delta t,\ R^2 = 0.69$
quadratic	$MR = A + Bt + ct^2$ $A = 1.004414 - 0.00038T - 0.00175H + 0.000051H^2 + 0.000107P$ $+0.00049\Delta t - 0.00006T\Delta t + 0.000014H\Delta t,\ R^2 = 0.87$ $B = -0.00097 - 0.00046T - 0.00031H + 0.000011H^2 - 0.00005P$ $+0.000483\Delta t + 0.000019T\Delta t + 0.000002HP - 0.00001H\Delta t,$ $R^2 = 0.94$ $C = 0.00027 + 0.000002T - 0.000002H - 0.00000003P -$ $0.00004\Delta t + 0.000001\Delta t^2,\ R^2 = 0.85$
two-term	$MR = A_1e^{-k_1t} + A_2e^{-k_2t}$ $A_1 = 0.93611 + 0.007626T - 0.00014T^2 - 0.00392H +$ $0.000283H^2 + 0.000328P - 0.02936\Delta t + 0.000858\Delta t^2,\ R^2 = 0.79$ $k_1 = 0.01033 + 0.00021T - 0.000009H + 0.00002P - 0.000948\Delta t,$ $R^2 = 0.80$ $A_2 = 0.138673 - 0.01052T + 0.000177T^2 + 0.000568H -$ $0.00019H^2 - 0.00009P + 0.025827\Delta t - 0.00066\Delta t^2,\ R^2 = 0.75$ $k_2 = 1.6849 + 0.00434T - 0.245274\ln T + 0.00457H -$ $0.052552\ln H + 0.00249P - 0.182479\ln P + 0.00527\Delta t -$ $0.119118\ln \Delta t,\ R^2 = 0.51$

[a] H, T, P and Δt stand for drying air absolute humidity(g/kg dry air), drying air temperature(℃), tempering time interval(min) and drying time interval(min), respectively.