

PADDY DRYING IN A VIBRATION-ASSISTED VACUUM INFRARED DRYER

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ABSTRACT

This study aimed to investigate the effect of vibration-assisted vacuum infrared (VVIR) drying on drying characteristics and quality of dried paddy of 12% (w.b.). The remoistened paddy of RD 47 variety with 25% (w.b.) and 10-mm grain bed depth was used in this study. The infrared intensities were 734, 853 and 952 W/m². The comparison of VVIR drying with vacuum infrared (VIR) drying and hot air (HA) drying (45-120°C) was also conducted. The results showed that VVIR drying at the infrared intensity of 734 W/m² provided high percentage of head rice yield (HRY) (38.31%), which was close to the HRY obtained by HA drying at 45°C (44.07%). However, the VVIR drying provided higher maximum drying rate and took shorter drying time (0.0108 ± 0.0003 g/g dry matter·min, 25 min) than those of the HA drying (0.0018 ± 0.0004 g/g dry matter·min, 360 min). VVIR and VIR drying also generated low paddy temperature of 40-50°C.

Keywords: Paddy; Infrared drying; Infrared radiation; Vibration; Vacuum drying

INTRODUCTION

Rice is a global staple food and has been considered as a significant agricultural product for Thai economy. The key discussion of rice post-harvesting is typically related to quality maximization. Harvested paddy has a moisture content in the range of 18 to 43% (d.b.). The drying process must be employed for a safe storage. However, this process has a considerable influence on development of internal cracking in the endosperm of the rice kernel which consequently results in kernel breakage during rice processing [1]. Hence, proper drying of paddy is necessary in order to maximize the rice yield and quality. Although many research has been done on paddy drying, research on new and/or hybrid drying systems for paddy drying is still required.

Far-infrared (FIR) drying has been reviewed as a potential method for drying various agricultural products such as fruits, vegetables and cereal grains. Under FIR drying, material can be dried directly by absorption of FIR radiation. Penetration of FIR radiation provides more uniform heating than heat transferred by hot air. Hence, moisture gradient and stress development in rice kernels during drying are reduced [2, 3]. However, penetration depth of

FIR radiation, i.e. 1-2 mm into grains, limits its ability to only surface heating application [3, 4]. Mechanical system like vibration would be useful to agitate rice grains in the bed to allow the grains to receive the radiation uniformly [5, 6]. Das and Bal found that the bed depth of paddy insignificantly affected the drying rate when drying the paddy in a vibration aided infrared dryer [4].

In addition, vacuum condition in the dryer leads to a lower boiling point of water. Drying at lower temperature is desirable and leads to prevention of a heat damage during the drying process.

Therefore, this study combined the advantages of vibration, vacuum drying and infrared radiation for paddy drying. Drying characteristics and quality of dried paddy undergoing VVIR drying were investigated and compared with those of the paddy subjected to VIR and HA drying.

MATERIALS AND METHODS

Paddy Sample

Paddy of RD47 variety was used as a sample of this study. Before using in each experiment, the paddy of 12% (w.b.) was

remoistened to the moisture content of 25% (w.b.) and kept at 4-5°C for 5-7 days to ensure uniform moisture throughout the kernels. The paddy was allowed to come to room temperature before drying.

Experimental Dryer

Figure 1 shows the experimental set-up of the VVIR dryer. A stainless steel drying chamber with inner dimensions of 21×29×3 cm³ was equally divided into six channels and covered with tempered glass. Type-K thermocouple was embedded on each channel of the drying chamber to measure the temperature of the paddy bed surface. An FIR heater (220 V, 700 W) was installed over the drying chamber to be operated at the infrared intensities of 734, 853 and 952 W/m² at the bed surface. An aluminum cover was placed on top of the FIR heater as an infrared reflector. The vibration system consisted of an eccentric joint with a speed-controlled motor (SF-JR, 0.4 kW, Mitsubishi, Thailand) and four helical springs. The drying chamber was vibrated at 800 rpm during operation. A vacuum pump (VE-290, Value, Zhejiang, China) was used to maintain absolute pressure of 5 kPa in the drying chamber during operation.

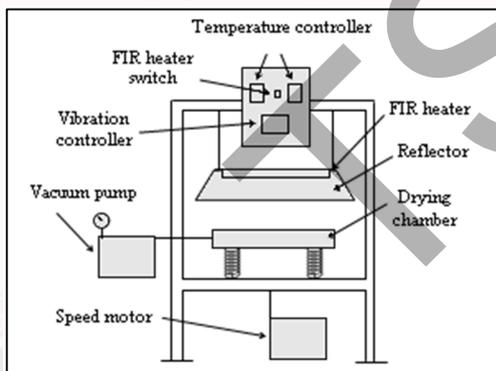


Fig.1 Schematic diagram of the VVIR dryer

Drying Procedure and Data Analysis

The VVIR drying experiments were performed at infrared intensities of 734, 853 and 952 W/m², vibration of 800 rpm and absolute pressure of 5 kPa. Before running each experiment, the infrared heater was allowed to stabilize for 5 min. The paddy of 10-mm grain bed depth (500 g) was then fed into the drying chamber and dried until its final moisture content reached about 12% (w.b.) For the VIR drying, no vibration was applied in the drying system. For comparison purposes, the conventional drying method, i.e. HA drying, was also conducted at temperatures of 45, 60,

90 and 120°C in a HA oven (ULM 500, Memmert GmbH+Co.KG, Schwabach, Germany).

During the process of drying, the dried paddy was sampled at predetermined intervals to measure its moisture content by HA drying at 130°C for 24 h [7].

The dimensionless moisture ratio (MR) and drying rate (DR) were calculated as follows:

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad \dots(1)$$

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad \dots(2)$$

where M_i , M_t , M_e and M_{t+dt} are moisture content (g/g dry matter) at initial, specific time, equilibrium and $t+dt$, respectively; and t is drying time (min).

As prolonged radiation yields burnt paddy, it was reasonable to omit M_e for VVIR and VIR drying [8]. The values of M_e for HA drying of paddy samples were determined using the following equation [9]:

$$M_e = \frac{1}{100} \left[\frac{\ln(1 - RH)}{C_1 T_{abs}} \right]^{1/C_2} \quad \dots(3)$$

where RH is relative humidity (decimal); T_{abs} is absolute temperature (°K); and C_1 and C_2 are equation constants, which are -3.146×10^{-6} and 2.464 for paddy, respectively. The M_e of the paddy samples subjected to HA drying at 45 and 60°C were 0.0017 and 0.0015 g/g dry matter respectively while HA drying at the temperatures of 90 and 120°C both provided the M_e of zero g/g dry matter.

Determination of Milling Quality of Dried Paddy

HRY and whiteness were determined. Head rice is defined as milled rice having a kernel length at least 80% of its original length. To measure HRY, 250 g of paddy was dehulled by a rubber roll huller (THU-35A, Satake Engineering Co., Ltd., Osaka, Japan), milled by a rice polisher (TM05, Satake Engineering Co., Ltd., Osaka, Japan) and graded to obtain whole grains and head rice by a rice grader (TRG 05A, Satake Engineering Co., Ltd., Osaka, Japan). Whiteness of milled rice was calculated using Equation (4). Color of milled rice in the CIE L* (lightness to darkness), a* (redness to greenness), b* (yellowness to blueness) system was obtained from a

spectrocolorimeter (MiniScan XE Plus, Hunter Associates Laboratory, Inc., Virginia, USA)

$$\text{Whiteness} = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2} \dots (4)$$

Statistical Analysis

All experiments were triplicate. The data were analyzed using the analysis of variance in a completely randomized design. Significant difference among treatment was determined using Duncan's multiple range test at 95% confidence interval.

RESULTS AND DISCUSSION

Drying Characteristics

Figures 2-4 illustrate the change in MR of paddy with time by VVIR, VIR and HA drying, respectively. As proposed by Toyoda [10], a paddy kernel could be considered to consist of two components, husk and a brown rice kernel, which are assumed to function as water tanks. During drying, the husk is mainly dried in the first short period. In the second longer period, brown rice kernel is principally dried and water transfer from brown rice to the air slows down. However, as seen in these figures, it is obvious that infrared radiation provided more uniform moisture transfer than hot air. It should be because of the absorption of infrared radiation inside the paddy kernel which promotes the migration of moisture from inside to surface of the kernel [2, 3].

As shown in Table 1, drying time decreased and maximum DR increased with increasing either infrared intensity or hot air temperature (Table 1). It appears that maximum DR of VVIR and VIR treatments were insignificantly different. They were also statistically the same as the maximum DR obtained by HA drying of paddy at the temperature of 120°C. VVIR drying at 952 W/m² provided the highest maximum DR of 0.0160 g/g dry matter·min, which was about 9 times higher than the lowest maximum DR of HA drying at 45°C. Shorter drying time and higher maximum DR of VVIR drying can be explained by uniform radiation created by a vibration system [5, 6]. Effect of vibration was more pronounced at the lowest infrared intensity of 734 W/m² as the largest difference between the drying times of VVIR and VIR drying at this infrared intensity was observed.

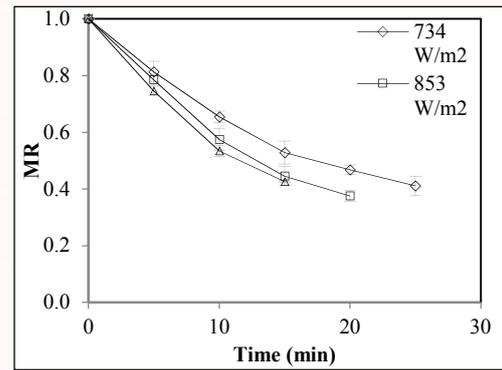


Fig. 2 Drying curves of VVIR drying of paddy at different infrared intensities

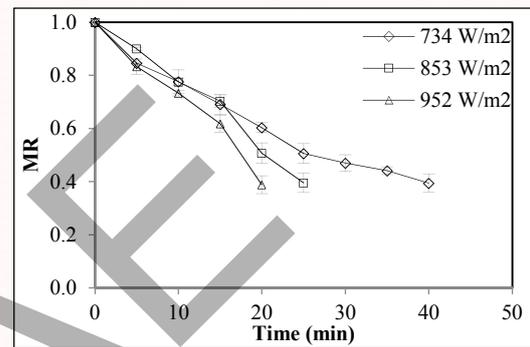


Fig. 3 Drying curves of VIR drying of paddy at different infrared intensities

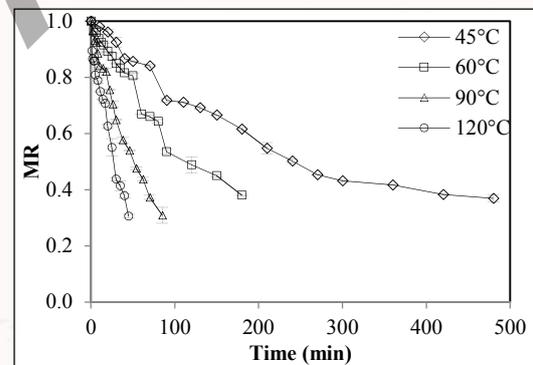


Fig. 4 Drying curves of HA drying of paddy at different drying temperatures

Final temperatures of paddy during drying are shown in Table 2. Final temperature of the paddy undergoing VVIR drying was slightly higher than that of the paddy undergoing VIR drying. It should be due to the effect of vibration which provided well-distributed radiation. It was also observed that infrared radiation could promote high value of maximum DR while generated low paddy temperature in the range of 40-50°C.

Drying condition	Drying time (min)	Maximum DR (g/g dry matter·min)
1. VVIR drying		
734 W/m ²	25	0.0108±0.0003 ^{abc}
853 W/m ²	20	0.0134±0.0008 ^{ab}
952 W/m ²	15	0.0160±0.0004 ^a
2. VIR drying		
734 W/m ²	40	0.0098±0.0010 ^{abc}
853 W/m ²	25	0.0102±0.0011 ^{abc}
952 W/m ²	20	0.0151±0.0016 ^a
3. HA drying		
45°C	360	0.0018±0.0004 ^d
60°C	150	0.0036±0.0017 ^{cd}
90°C	70	0.0064±0.0010 ^{bcd}
120°C	40	0.0104±0.0097 ^{abc}

Different superscripts in the same column mean that the values are significantly different ($p \leq 0.05$).

Table 2 Final temperatures of dried paddy under-going VVIR, VIR and HA drying

Drying condition	Final temperature of dried paddy (°C)
1. VVIR drying	
734 W/m ²	44.50±1.97 ^f
853 W/m ²	49.67±1.51 ^d
952 W/m ²	48.33±1.03 ^{de}
2. VIR drying	
734 W/m ²	40.83±1.94 ^g
853 W/m ²	47.33±1.86 ^e
952 W/m ²	46.83±1.47 ^e
3. HA drying	
45°C	42.50±0.41 ^g
60°C	56.00±0.41 ^c
90°C	80.12±0.85 ^b
120°C	107.38±0.48 ^a
1. VVIR drying	
734 W/m ²	44.50±1.97 ^f
853 W/m ²	49.67±1.51 ^d
952 W/m ²	48.33±1.03 ^{de}
2. VIR drying	
734 W/m ²	40.83±1.94 ^g
853 W/m ²	47.33±1.86 ^e
952 W/m ²	46.83±1.47 ^e
3. HA drying	
45°C	42.50±0.41 ^g
60°C	56.00±0.41 ^c
90°C	80.12±0.85 ^b
120°C	107.38±0.48 ^a

Different superscripts in the same column mean that the values are significantly different ($p \leq 0.05$).

Milling Quality of Paddy

The milling quality of dried paddy in terms of HRY and whiteness are shown in Table 3. The higher drying condition (either infrared intensity or drying temperature), the greater the HRY lost. The highest percentage of HRY was obtained by HA drying at 45°C, the lowest drying temperature used in this study. The second highest percentage of HRY was

provided by VVIR drying at 734 W/m². It is important to notice that the latter can be operated faster (more than 14 times faster than the 45°C HA drying).

Comparing between VIR drying at 734 W/m² and HA drying at 120°C, which took the same drying time of 40 min, HRY of paddy subjected to the VIR drying was about 2.6 times greater than that of the HA drying. Meeso et al. suggested that FIR heating provides simultaneous moisture removal and moisture leveling [11]. Hence, moisture gradient and stress development within the paddy kernel decrease and HRY could be maintained.

Whiteness of dried paddy was in the range of 60-67%. Drying time was an important factor affecting the whiteness of paddy. In the same drying method, the shorter drying time caused a higher value of whiteness, except the HA drying, of which the peak level of whiteness was obtained at the drying temperature of 90°C. It should be note that an increase in infrared intensity or drying temperature which led to a decrease in drying time consequently resulted in a higher value of whiteness. These results are in contrast with those reported by Taechapiroj et al. for superheated steam fluidized bed drying of paddy; higher drying temperature led to lower whiteness value [12].

Table 3 HRY and whiteness percentages of dried paddy undergoing VVIR, VIR and HA drying

Drying condition	HRY (%)	Whiteness (%)
1. VVIR drying		
734 W/m ²	38.31±1.63 ^b	61.83±0.69 ^{de}
853 W/m ²	31.00±1.48 ^c	62.52±0.54 ^{cd}
952 W/m ²	28.34±0.89 ^c	64.99±0.79 ^b
2. VIR drying		
734 W/m ²	35.41±2.70 ^b	63.21±0.62 ^c
853 W/m ²	28.31±3.44 ^c	63.42±0.29 ^c
952 W/m ²	21.08±0.13 ^d	64.68±0.37 ^b
3. HA drying		
45°C	44.07±0.97 ^a	60.08±0.48 ^f
60°C	30.60±3.09 ^c	60.82±0.01 ^{ef}
90°C	17.79±0.49 ^e	67.08±0.18 ^a
120°C	13.57±0.78 ^f	65.23±0.56 ^b

Different superscripts in the same column mean that the values are significantly different ($p \leq 0.05$).

CONCLUSIONS

In average, VVIR drying provided the highest maximum DR, followed by VIR drying and HA drying, respectively. VVIR and VIR drying also required shorter drying time while

generated lower paddy temperature than HA drying. HA drying at low temperature of 45°C was the best way to preserve HRY of paddy. However, it took about 14 times longer than VVIR drying at 734 W/m², which offered the second highest percentage of HRY. Whiteness of milled rice was higher when drying time of paddy was shorter.

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