21st International Drying Symposium
IDS'2018

IDS'2018 – 21st International Drying Symposium
València, Spain, 11-14 September 2018
DOI: http://dx.doi.org/10.4995/ids2018.2018.7541

Process of parboiling rice by microwave-assisted hot air fluidized bed technique

Prachayawarakorn, S.[a*]; Saniso, E.[b]; Swasdisewi, T.[c]; Soponronnarit, S.[d.]
[a]Department of Chemical Engineering. Faculty of Engineering. King Mongkut's University of Technology Thonburi, 126 Pracha-Uthid Road, Bang Mod, Thung khru, Bangkok 10140, Thailand.
[b]Division of Physics, Faculty of Science Technology and Agriculture, Yala Rajabhat University, 133 Tesaban Road 3, Amphur Muang, Yala 95000, Thailand.
[c]Division of Thermal Technology, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi, 126 Pracha-Uthid Road, Bang Mod, Thung khru, Bangkok 10140, Thailand.
[d]Division of Energy Technology, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi, 126 Pracha-Uthid Road, Bang Mod, Thung khru, Bangkok 10140, Thailand.

*E-mail of the corresponding author: somkiat.pra@kmutt.ac.th

Abstract

In this work the new process of producing parboiled rice (PB) by combinatintion of microwave and hot air fluidized bed (MWFB) was proposed and investigated. Results showed that the drying time was shorter with smaller bed depth, higher drying temperature and higher microwave power. The initial grain temperature, drying temperature, bed depth and microwave power strongly affected the gelatinization of rice starch. The PB produced by MWFB caused a very small broken kernel (1-2%). The whiteness was decreased with increase in drying time, initial grain temperature, drying temperature and microwave power. The specific energy consumption was increased with increasing such operating parameters.

Keywords: *Drying; Parboiled rice; Fluidized bed; Microwave.*

1. Introduction

PB producion in the industrial scale around the world can normally be done by wet-heat process. This process mainly consists of soaking, steaming and drying step. In the steaming step, the saturated steam, normally produced by high pressure boiler, is used to gelatinize the rice starch [1]. After steming, the rice starch appears transulance. In addition to the wet heat process, the dry heat process is also used in a small scale factory. By the dry-heat process, hot air or roasting with or without sand is practicall utilized. The later process involves conduction heating of moisten paddy at a higher temperature with shorter drying duration. The starch gelatinization with no retrogradation is specifically found, unlike to the wet heat process, because of the simultaneous rapid loss of water from the paddy during conduction heating was studied by Mahanta and Bhattachaya [2]. Pillaiyar et al. [3] reported that the roasting sand at temperature of 125°C could get the fully PB but with mild effect. The parboiling became severe at high temperatures. Roasting the soaked paddy at 250°C could reduce the cooking time of the PB. A sand temperature of 125-150°C is considered as suitable condition for producing PB by this technique

The wet-heat PB production requires many components such as the boiler, steam pipe and auxiliary devices, while the dry-heat PB process using sand roasting [4] needs to separate the paddy-sand mixture after parboiling. To eliminate the restrictions on the steaming and sand separation in PB production, the MWFB was proposed and investigated. The microwave (MW) drying has been studied by many researchers and applied with many products. But, the work involing with parboiling rice is still limited in the literature. It appears only work reported by Kahyaoglu et al. [5] for parboiling wheat using MW-assisted spouted bed drying. They found that the MW-assisted spouted bed drying at the MW power of 3.5 and 7.5 W/g reduced drying time by at least 60% and 85%, respectively compared to spouted bed drying. As mentioned above, in this work, the new process of producing PB by MWFB was proposed and investigated. In the experiment, the drying kinetics and quality of head rice yield (HRY), the degree of starch gelatinization (DSG), morphology, whiteness value and specific energy consumption (SEC) were investigated.

2. Materials and Methods

2.1. Materials

The Suphanburi 1 paddy variety was stored at ambient air temperature for 6 months. Paddy was soaked at the temperature of 69±1°C for 5 h (47±1% d.b.) and different initial grain temperatures of 32, 55 and 65°C was dried by MWFB and FB dryers.

2.2. MWFB dryer

Fig. 1 shows the MWFB dryer. The system consists of a stainless steel cylindrical drying chamber with an inner diameter of 21 cm and height of 80 cm, a 19 kW electric heaters, a backward-curved blade centrifugal fan driven by a 2.2 kW (3 HP) motor and 5 MW magnetrons with each rated at 800 W (2.45 GHz). The magnetrons were installed at 5.5, 11.5, 17.5, 23.5 and 30.0 cm above distributor plate of the drying chamber.

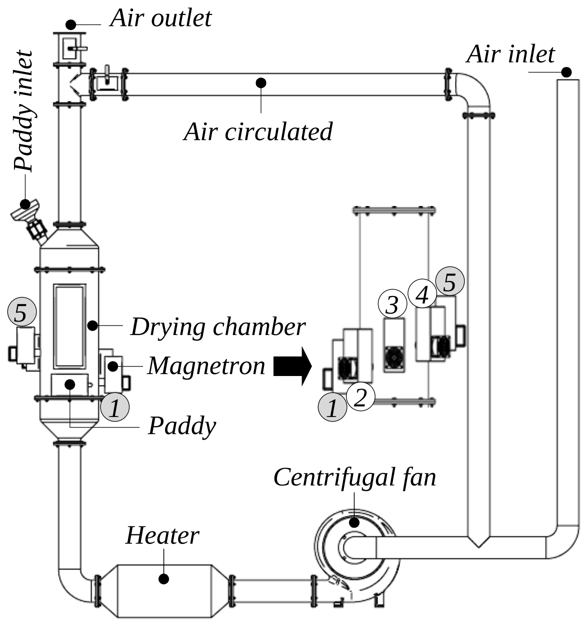

Fig. 1 A schematic diagram of a MWFB dryer.

2.3. Experimental design

The soaked paddy was dried by MWFB and FB at temperatures of 130, 150 and 170°C with a MW power of 1.6, 2.4 and 4.0 kW. Bed depth of 5 and 10 cm, as well as an inlet superficial air velocity of 4.6 m/s and recycled exhaust air fraction of 0.8 were used. After reaching predetermined drying time, the paddy was taken out from the dryer and the samples were gently dried in shade to obtain a final moisture content of 15±1% d.b. The experiment was performed in duplication. The MC of paddy was determined acording to AACC 1995 [6] method at a temperature of 103±2°C for 72 h. It was done in triplicate and the mean value was reported.

The dried paddy sample (150±1 g) was dehusked using a rubber roll hulling machine (Ngeksenghuat, model P-1, Thailand) and milled rice to remove bran using a miller (Ngeksenghuat, model K-1, Thailand). Whole and broken grains were graded automatically using a cylindrical rice separator (Ngeksenghuat, model I-1, Thailand). The milling test was performed in duplicate and the HRY was calculated by the following equation.

$$\%HRY = \frac{W_{hr}}{W_p} \times 100 \quad (1)$$

where W_{hr} is mass of head rice sample (g) and W_p is mass of paddy sample (g).

The DSG of the rice samples was characterized by the Differential Scanning Calorimeter (DSC) (Perkin Elmer, model DSC-7, USA). A sample was ground into powder and 3 mg rice flour sample was put into an aluminium pan and mixed with 10 mL distilled water. The pan was sealed and kept to equilibrate at room temperature for 1 h. After that, the sample was heated from 40 to 110°C at a scanning rate of 10°C/min. The determinations were done duplication and the DSG was calculated by the following equation.

$$\%DSG = \left[1 - \frac{\Delta H}{\Delta H_C}\right] \times 100 \quad (2)$$

where ΔH is the enthalpy change of starch in dried rice (J/g dry matter) and ΔH_c is the enthalpy change of reference rice starch (J/g dry matter).

The scanning electron microscope (SEM) (JEOL, model JSM-6610LV, Japan) with accelerating voltage 5 kV was used to examine the starch granules morphology. Before test, the sample was attached to an SEM stub and coated by sputter coater (Cressington, model 108 Auto, UK) with a pure copper 99.99% layer. While, the whiteness of rice samples was determined by a Kett digital whiteness meter (model C-300, Japan). Before measuring, the whiteness meter was calibrated with a white colored reference that has a standard value of 86.3. Each measurement was performed in 10 replicates and the mean value was reported.

3. Results and Discussion

3.1 Drying characteristics

The experimental results showed that the bed depth of 5 cm, the grain temperature was significantly higher than that at the bed depth of 10 cm approximated by 5-15°C. With the MWFB drying, it could reduce MC faster than the FB drying by approximately 2-5% d.b. When the grain gets the MW, the water molecules are rapidly rotated by MW frequencies (2.45 GHz). The heat is rapidly generated, especially in the middle of the paddy grain. As a result, the grain temperature in the MWFB was significantly higher than that of FB about 5-10°C. The higher grain temperature in the MWFB can accelerate the travel of moisture from the inside to the external, resulting in higher rate of drying [8].

At the same time, the drying time to reach an intermediate MC of 20±2% d.b. was shorter with smaller bed depth, higher drying temperature and higher MW power, as shown in Fig. 2(a). Considering the effect of initial grain temperature as shown in Fig. 2(b), the drying rate for the grain temperature of the paddy sample that had higher initial grain temperature was insignificantly different from that of the sample with lower initial grain temperature although the grain temperature at higher intial grain temperature was higher during drying. This is possibly due to the fact that the moisture movement during drying might be in the liquid form and controlled by liquid diffusion. In the liquid diffusion, the variation of temperature between 32 and 65°C does not provide a big difference of effective diffusion coefficient of water (only 1-2% d.b. moisture difference).

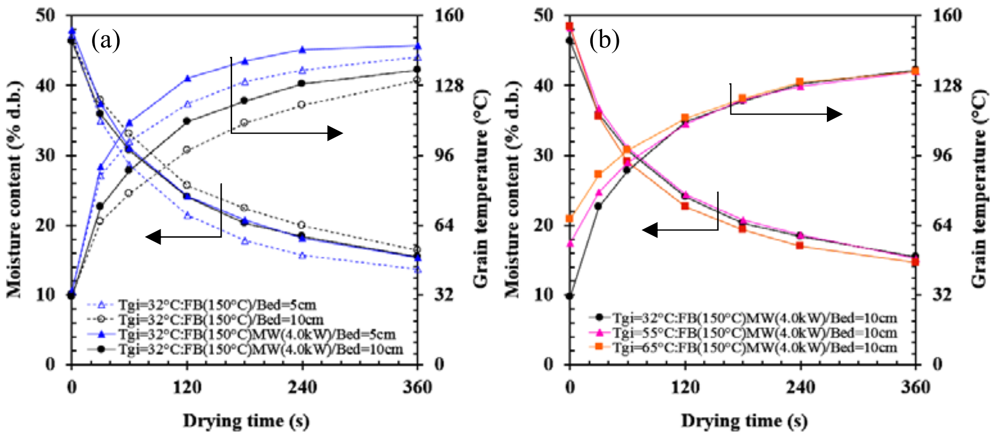

***Fig. 2** Evalution of MC and grain temperature of soaked paddy dried by FB and MWFB.*

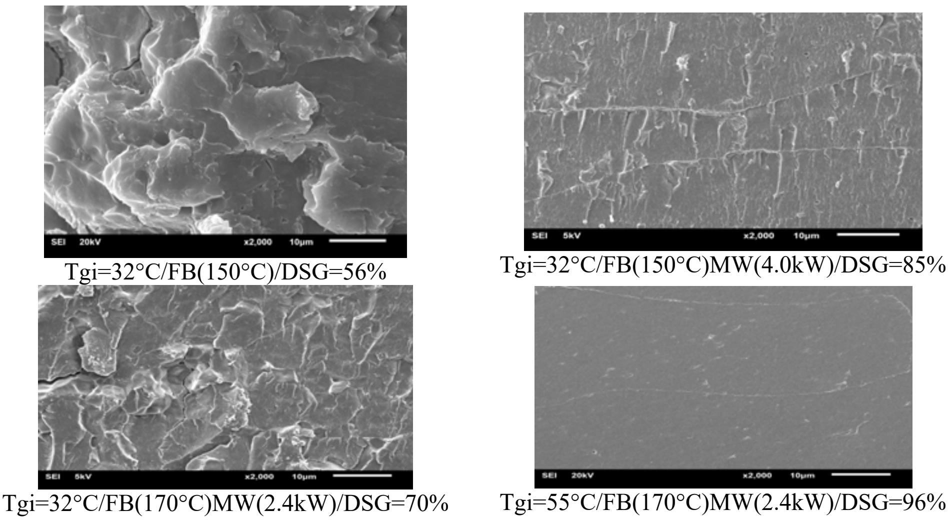

***Fig. 3** SEM images at the interior area of soaked paddy dried by FB and MWFB (Bed=10 cm)*

3.2 Degree of starch gelatinization

The use of FB drying at the temperature of 130-170°C allowed starch to be gelatinized in a range of 41-65% for initial grain temperatures of 32°C and 10 cm bed depth. At this DSG range, the PB is classified as the mildly PB [8] and the kernel that appeared white belly was not found although the starch gelatinization was incomplete. As the soaked paddy was dried at the bed depth of 5 cm, the rice starch was gelatinized in a range of 48-100%, depending on the drying temperature. The FB drying at 170°C could produce the severely PB.

As the MW(4.0kW) was combined with FB, the PB dried at the temperature of 150°C or higher was designated as severely PB. The complete gelatinization of rice starch was found with the soaked paddy dried by FB(170°C)MW(4.0kW), FB(150°C)MW(4.0kW), FB(170°C)MW(2.4kW) when the initial grain temperatures of 32, 65 and 65°C, respectively, was employed at the bed depth of 10 cm. Also the soaked paddy dried by FB(170°C) and FB(170°C)MW(4.0kW) at initial grain temperature of 32°C and bed depth of 5 cm had complete gelatinization of rice starch as shown in Table 1.

3.3 Morphology

Fig. 3 show the starch granules of the soaked paddy dried by FB(150°C) and MW(4.0 kW)FB(150°C) with initial grain temperature of 32°C, it seem that some starch granules still appeared at the interior of the rice kernel when the soaked paddy dried by FB only whereas the starch granules of the soaked paddy dried by MWFB were smooth with the complete loss of granular morphology of the rice.

In case of soaked paddy at the initial grain temperatures of 32 and 55°C dried by MW(2.4 kW)FB(170°C), some starch granules still appeared at the at the interior of the rice kernel when the soaked paddy dried at initial grain temperature of 32°C whereas the starch granules of the soaked paddy dried at initial grain temperature of 55°C were smoothest with the complete loss of granular morphology of the rice, indicating the complete starch gelatinization. This is consistent with the result of degree of starch gelatinization.

3.4 Head rice yield

Table 1 shows the HRY of PB produced by MWFB yielded a very small broken kernel (1-2%) after drying with including tempering at the drying temperature above 130°C for MW powers of 2.4 and 4.0 kW. The small broken kernel can be attributed to the higher DSG. Hiowever, considering the initial grain temperature effect, this parameter did not much effect on the HRY, the value laying between 68 and 70%. However, the operation of MW(4.0 kW)FB(170°C) must be avoided although the starch gelatinization was completed. This is because the grain temperature dried at this condition was raised to 150°C causing the grains to be puffed and resulting lower HRY.

3.5 Colour

The whiteness value of PB was decreased with increase in initial grain temperature, drying temperature and MW power and with decreasing bed depth as shown in Table 1 for both tempering and no tempering. The whiteness value of MWFB drying was significantly lower than that of FB drying at the same initial grain temperature, drying temperature and MW power because the paddy grain temperature in the MWFB drying is higher than that of FB drying. The higher grain temperature time more accelerates a higher rate of Maillard reaction [9]. The PB samples that falled in the severely PB category (DSG>70) had yellowish brown colour (Gold parboiled rice), which corresponded to the whitness value of 22-24. When the soaked paddy was dried by at 170ºC, MW power of 4.0 kW and at a bed depth of 5 cm, the product colour was reddish, which was unacceptable in the market.

3.6 Specific energy consumption

Considering in Table 1, it was found that drying the soaked paddy at the initial grain temperature 32ºC at 170ºC and at bed depth of 5 cm spent the SEC of 4.6 MJ/$kg_{water\ evap.}$

Table 1. DSG, HRY, SEC and whiteness of soaked paddy dryied by FB and MWFB.

Drying conditions		DSG (%)	HRY (%) T	HRY (%) NT	Whiteness T	Whiteness NT	SEC (MJ/kg_{water} evap.)
Bed = 10 cm	*Initial grain temperature of 32ºC*						
	FB(130ºC)	41.1	68.8	64.3	27.3	31.6	-
	FB(150ºC)	55.6	69.4	65.4	25.1	29.5	-
	FB(170ºC)	65.5	71.3	70.0	25.8	31.0	-
	FB(130ºC)MW(4.0kW)	60.5	69.7	65.6	25.2	28.5	-
	FB(150ºC)MW(4.0kW)	85.2	69.2	67.3	21.9	25.7	10.1
	FB(170ºC)MW(2.4kW)	69.7	70.1	68.1	23.3	21.5	-
	FB(170ºC)MW(4.0kW)	100.0	71.9	70.5	23.3	26.4	7.6
	Initial grain temperature of 55ºC						
	FB(150ºC)MW(4.0kW)	94.3	69.9	67.8	21.1	25.6	10.1
	FB(170ºC)MW(1.6kW)	85.9	69.8	67.9	23.9	25.2	-
	FB(170ºC)MW(2.4kW)	95.8	70.6	68.8	21.0	26.5	5.1
	Initial grain temperature of 65ºC						
	FB(170ºC)	83.9	69.5	66.5	24.4	29.2	-
	FB(130ºC)MW(4.0kW)	70.6	68.5	65.6	24.3	27.3	-
	FB(150ºC)MW(2.4kW)	72.8	69.8	67.3	20.3	24.9	-
	FB(150ºC)MW(4.0kW)	100.0	70.4	67.5	21.0	23.1	10.0
	FB(170ºC)MW(1.6kW)	92.9	69.6	67.7	21.3	23.5	-
	FB(170ºC)MW(2.4kW)	100.0	70.5	68.9	20.3	22.8	5.1
Bed = 5 cm	*Initial grain temperature of 32ºC*						
	FB(130ºC)	48.6	69.7	65.5	24.0	25.6	-
	FB(150ºC)	80.4	71.5	69.7	21.1	24.3	-
	FB(170ºC)	100.0	69.2	68.4	16.4	22.9	4.6
	FB(130ºC)MW(4.0kW)	70.2	68.9	65.5	18.7	23.2	-
	FB(150ºC)MW(4.0kW)	91.2	70.6	69.8	17.8	23.5	-
	FB(170ºC)MW(4.0kW)	100.0	65.6	59.4	12.5	17.8	10.8
Traditional method		100.0	70.0-71.5		21.5-26.2		6.4-7.5
Raw rice		0.0	-	50.3	-	45.2	-
Soaked rice		7.8	-	52.8	-	37.0	-

Bed = Bed depth, T = Tempering, NT = No tempering

This SEC was significantly lower than that dried by FB(170ºC)MW(4.0kW) by 57% and less than the SEC from the traditional PB production by 32%. The use of higher initial grain temperature (65°C) could reduce the MW power to 2.4 kW and the SEC was reduced by 27% as compared to the traditional method

4. Conclusions

The MWFB could produce PB with a complete degree of starch gelatinization without the need of steam for parboiling rice. This makes it easier to produce PB and reduces the complexity and size of the plant. The production of PB with FB(170°C) alone at initial grain temperature of 32°C and bed depth of 5 cm have lower SEC than the traditional PB production by 32%. The increasing initial grain temperature up to 55 and 65°C for soaked paddy dried by FB(170°C)MW(2.4kW) at the bed depth of 10 cm could reduce the SEC in the production of PB by 27% as compared to the traditional method.

5. Acknowledgements

The authors express their sincere appreciation to The Office Of The Higher Education Commission (OHEC) and Yala Rajabhat University (YRU), Thailand. Also, the authors thanks to The Thailand Research Fund (TRF) and The Thailand Research Fund (Grant no. DPG5980004), for their financial support.

5. References

[1] Bhattachaya, S. Kinetics on colour changes in rice due to parboiling. Journal of Food Engineering 1996, 29(1), 99-106.

[2] Mahanta, C.L.; Bhattacharya, K.R. Relationship of starch changes to puffing expansion of parboiled rice. J Food Sci Technol 2010, 47(2), 182-187.

[3] Pillaiyar, P.; Singaravadivel, K.; Desikachar, H.S.R. Quality changes in HTST processing of rice parboiling. J Sci Food Agric 1994, 65, 229-231.

[4] Ali, S.Z.; Bhawacharya, K.R. High-temperature drying-cum. Parboiling of paddy. Journal of Food Process Engineering 1980, 4, 123-136.

[5] Kahyaoglu, L.N.; Sahin, S.; Sumnu, G. Spouted bed and microwave-assisted spouted bed drying of parboiled wheat. Food and bioproducts processing 2012, 90(2), 301-308.

[6] AACC. Approved method of the American association of cereal chemists (9th ed.). MN: American Association of Cereal Chemists: St. Paul, 1995.

[7] Rattanadecho, P.; Makul, N. Microwave-assisted drying: a review of the state of the art. Drying Technology: An International Journal 2016, 34(1), 1-38.

[8] Lamberts, L.; De Bie, E.; Derycke, V.; Veraverbeke, W.S.; De Man, W.; Delcour, J.A. Effect of Processing Conditions on color change of brown and milled parboiled rice. Cereal Chemistry 2006, 83(1), 80-85.

[9] Lamberts, L.; Rombouts, I.; Brijs, K.; Gebruers, K.; Delcour, J. A. Impact of parboiling conditions on maillard precursors and indicators in long-grain rice cultivars. Food Chemistry 2008, 110(4), 916-922.