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# Energy consumption and qualitative evaluation of a continuous band microwave dryer for rice paddy drying

Hassan Jafari [a], Davood Kalantari [a, *], Mohsen Azadbakht [b]

[a] Department of Bio-systems Engineering, Sari Agricultural Sciences and Natural Resources University (SANRU), Sari, Iran
[b] Department of Bio-systems Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

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ABSTRACT

In this study, a laboratory scale continuous-band microwave dryer was fabricated and used for drying the paddy. The experiments were carried out at 3 microwave powers (90, 270, and 450 W), conveyor speed 0.24 m/min, and 3 paddy layer thicknesses (6, 12, and 18 mm). The penetration depth of the waves into the examined paddy was obtained equal to 12.7 mm at 25.46% moisture content (w.b %). The maximum energy absorption (81.46%) was obtained at 90 W power and 18 mm layer, whereas the minimum energy absorption was obtained equal to 34.90% at 6 mm paddy thickness and 270 W microwave power. The obtained results indicated that the maximum energy efficiency, the maximum thermal efficiency, the maximum drying efficiency, the minimum specific energy consumption, and the minimum seed breakage percent occurred at 90 W microwave power and 18 mm drying thickness. Therefore as a final concluding result, drying thickness of 18 mm and microwave power of 90 W was selected as the most appropriate combination for drying paddy using the continuous band microwave dryer.



## 1. Introduction

Since very long ago, rice has been distinguished as one of the oldest and most important foodstuffs for a human. Todays, almost one-third of the world population rely on rice as a main food source. In Iran, rice is the most important food after wheat, therefore a wide range of Iran's lands is annually devoted to planting this valuable crop. In the food processing chain, paddy must pass through different steps such as drying, husking, witting, and sorting in order to be usable. One of the most critical steps that must be carried out during the paddy processing is drying operation. Paddy has high moisture content at the harvesting time which is about 25–28% on the wet basis [1,2]. Scientific and technical principles in the process of drying paddy have been attempting to increase the efficiency of converting paddy into white rice as well as better and longer maintenance of the crop during storage. Suitable moisture content for paddy storage or paddy husking is about 14% or even less on the wet basis [1]. In microwave dryers, microwave radiation is used for drying the crops. The microwave is a magnetic wave with the frequency in the range of 300–300000 MHz and wave length of 1 m to 1 mm [3]. In heating by microwave, the combination of electromagnetic field polarizes the molecules of dielectric materials and forms a bipolar torque which causes the rotation of these molecules. Intermolecular friction caused by these rotations causes heat generation inside the crop [4]. The advantages of using microwave over the conventional drying methods include consuming less energy than the conventional methods, more penetration of waves into foodstuff and moisture spread in the whole mass of foodstuff instead of surface moisture evaporation. During the conventional drying, e.g., in a convective dryer, moisture first evaporates from the crop surface. Meanwhile, internal moisture spread from the seed's kernel to its surface based on the diffusion phenomena, which is very slow. However, in microwave drying, internal heat generation in the crop leads to increased internal temperature and pressure, both of which accelerate the fluid flow to the crop surface; therefore, drying rate is increased. The remarkable point is that most of the applied microwave energy appears as temperature rise in the foodstuff. Because of the low dielectric constant of dryer components, there is a minimum energy transfer to other components of the microwave dryers such as dryer wall, conveyor band, and other parts. Drying time by microwave equipment can decrease by up to 50% or more, which depends on the crops and drying conditions [5–8]. Drying process by microwave depends on crop type and its dielectric properties. Heat

* Corresponding author.
*E-mail address:* d.kalantari@sanru.ac.ir (D. Kalantari).

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**Nomenclature**

| | |
|---|---|
| MC | Moisture content (w.b. %) |
| $W_w$ | the weight of the wet crop (kg) |
| $W_d$ | Weight of the dried crop (kg) |
| MR | Moisture ratio (dimension less) |
| $MC_t$ | Moisture content at time "t" (w.b. %) |
| $MC_e$ | Equilibrium moisture content (w.b. %) |
| $C_p$ | Specific heat capacity (kJ/kg K) |
| T | Crop temperature (K) |
| $D_p$ | Penetration depth (m) |
| $\varepsilon'$ | Relative dielectric constant |
| $\varepsilon''$ | Relative dielectric loss factor |
| $v$ | Velocity of propagation (m/sec) |
| f | Microwave frequency (Hz) |
| $P_T$ | Absorbed microwave power (kw) |
| $\Delta T$ | temperature Increment (K) |
| t | Heating time (sec) |
| $\eta$ | Energy efficiency (%) |
| $Q_{eva}$ | Energy consumed for moisture evaporation (kJ) |
| $E_{del}$ | Energy delivered to device (kJ) |
| $\eta_{th}$ | Thermal efficiency (%) |
| D | Weight density (kg/m$^2$) |
| A | Tray area (m$^2$) |
| $h_{fg}$ | Latent heat of vaporization (kJ/kg) |
| $M_f$ | Final moisture content (w.b. %) |
| Z | Power delivered to the device (kW) |
| $\eta_{Dr}$ | Drying efficiency (%) |
| $Q_{tem}$ | Energy consumed for the temperature increment (kJ) |
| $Q_{total}$ | Total consumed energy (kJ) |
| $W_{eva}$ | Amount of evaporated moisture (kg) |
| SEC | Specific energy consumption (kJ/kg) |
| $P_{Mg}$ | Electrical power supplied to magnetrons (kw) |
| $P_{bf}$ | Consumed electrical power by blower fans (kw) |
| $P_{sf}$ | Consumed electrical power by suction fan (kw) |
| $P_{em}$ | Consumed electrical power by electro-motor (kw) |

loss in microwave dryer depends on different parameters such as type of crop, microwave power level, microwave's wave distribution inside the cavity, and dielectric features of crop and its bed [9]. Energy consumption and drying efficiency are among the most important indexes of drying agricultural crops and foodstuff [10,11]. So far, some studies have been performed on the behavior of agricultural crops and energy analysis by microwave dryers. Results obtained from these studies showed that, by increasing microwave power, the moisture of the crops decreased at a faster rate. Jindarat et al. (2011) and Motevali et al. (2014) have represented that energy efficiency is decreasing with the increase of microwave power, while energy consumption is increasing [9–11]. However, studies have not been performed for investigating the drying energy analysis of paddy using a continuous band microwave dryer.

The aims of this research are to investigate temperature changes of the crop during drying, absorbed energy by the crop, energy efficiency, thermal efficiency, dryer efficiency and qualitative properties of the examined paddy such as seed breakage percent, using a continuous band microwave dryer.

## 2. Materials and methods

In this research, a semi-industrial continuous band microwave dryer was fabricated in Department of Biosystems Engineering at SANRU (Fig. 1). Tarom Hashemi cultivar was used in this research as drying substance. Tarom Hashemi is one of the most common cultivars in the north of Iran [12].

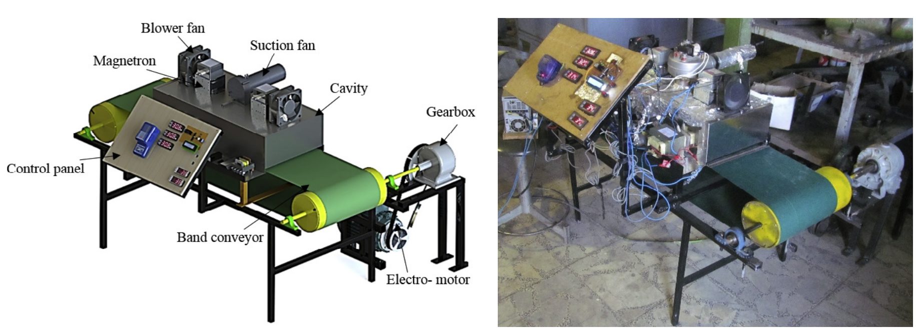
The moisture content of paddy was measured using an oven at 103 °C for 48 h [13]. Initial moisture content of the examined paddy was 25.46% on the wet basis.

For temperature measurement of the grains before and after drying, temperature of 10 randomly chosen grains at the entrance and exit of the dryer were measured using a needle type thermometer (testo 103, Germany). Measurements has been performed at three points on the grain (top, middle, and down) and in the cross section of each grain (after dividing the grain into 2 broken parts). Average of the measured data were chosen as the grain temperature. Each experiment has been performed in three replications.

The fabricated microwave dryer had 10 different output powers ranging between 90 and 900 W. The experiments were carried out at 3 microwave output power levels of 90, 270, and 450 W, conveyor speed of 0.24 m/min, and 3 drying thickness of 6, 12, and 18 mm. The paddy samples with the constant weight of 30 g were used in the experiments. The moisture content of the dried samples was determined using the following equation [11]:

$$MC_t = \frac{w_w - w_d}{w_w} \tag{1}$$

where $W_w$ is the weight of the wet crop (kg) and $W_d$ is the weight of the dried crop (kg).




(a) (b)

**Fig. 1.** (a) 3D model and (b) Real image of the examined continues band microwave dryer.