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Microwave power control strategies on the drying process I. Development and evaluation of new microwave drying system

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Abstract

A phase-controlled electrical power regulator was developed and connected in series with the original cycle-controlled power regulator of an existing domestic microwave oven. The microwave oven was further modified such that combined microwave and convectional drying can be accommodated. The system performance was evaluated which included calibration of the maximum microwave output power, determination of the microwave distribution in the cavity, establishment of the relations between the output power and the input voltage for the phase-controlled power regulator. It was observed that phase-controlled power regulator could be successfully used for quasi-continuous (fast-switching) power regulation with the maximization of power efficiency. The degradation of output microwave power was recorded and the non-uniform distribution of microwave field in the cavity was also verified.

Keywords: Microwave power; Phase control; Cycle control

1. Introduction

The application of microwaves has been of increasing interest in processing of foods and bio-commodities over past two decades. During microwave drying process local pressure and temperature rise continuously even though the loss factor of treated materials decrease with the reduction of moisture content. Although these increases of pressure and temperature can speed up the drying process, they may cause side effects such as bio-value degradation, physical damages, and non-uniform temperature distribution in treated materials.

The fact that the input electrical power or the output microwave power governs the quality of final products has led many researchers to study the relationship among them. Shivhare, Raghavan, Bosisio, and Mujumdar (1992a) employed intermittent microwave operation in corn drying, the data indicated that seed quality corn could be obtained using 5 min on and 15 min off pulse at 0.5 W/g absorbed power. Shivhare, Raghavan, and Bosisio (1992b) claimed the microwave power density should be less than 0.25 W/g if seed-grade corn is desired during continuous microwave drying. Prabhanjan, Ramaswamy, and Raghavan (1995) observed that a power level of 50% (rated power of 600 W) caused burning of the product in microwave drying of carrots. Venkatachalapathy and Raghavan (2000) found that at 40% power duty cycles (rated power of 600 W), there was burning of the dried strawberry in microwave drying of whole strawberries. Sunjka (2003) conducted intermittent microwave drying of cranberries and the results illustrated that for obtaining higher quality dried cranberries, pulsed modes with longer power-off time

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(30 s on and 45 s off), higher power density and lower system pressure should be applied. Similar studies were also carried out by Raghavan, Alvo, and Shivare (1993) in microwave drying of cereal grain, and Raghavan and Silveira (2001) in microwave drying of strawberries. These studies optimized microwave drying processes and, as a result, product qualities were improved.

Extensive research studies have been done on the optimization of drying process either by integral cycle control (intermittent or ON/OFF microwave operation) or by linear resistive control (continuous microwave operation) of input electrical power. However, no report emphasized the effects of other input electrical power control methods, such as fast switching method, on the microwave drying process. Actually, each power control method produced its own unique time-varying supply voltage waveforms (profiles). Different supply voltage waveform may give different effects on the microwave drying process. Hence there is a need to investigate their impact on drying performance.

The main objective of this study is to evaluate the effects of two different input electrical power control methods, phase control and cycle control, on the microwave/air drying process. The secondary objective is to evaluate the system performance which includes calibration of the maximum microwave output power, determination of the microwave distribution in the cavity, and establishment of the relations between the output power and the input voltage for the phase-controlled power regulator.

2. Materials and methods

2.1. Microwave drying system

Microwave drying system was developed based on a commercial microwave oven (Magnasonic MMMW5730, LG Electronic Inc., Korea) with nominal power of 700 W at 2,450 MHz. Dimensions of cavity are $300 \times 195 \times 290$ mm ($L \times H \times W$) with the volume of 0.117 m^3. The original control set-up (power regulator) in the microwave oven included a power switch and a timer. The power regulator worked based on the integral cycle control method, that is, power level is either 100% or 0% of rated values. The developmental work included development of microwave drying setup, design of a triac phase-controlled power regulator, and modification of original electrical circuit.

2.2. Development of microwave drying setup

An air heating and blowing system was introduced for the purpose of coupling microwave with air drying. As the first step, the turnable was dismantled and removed from the cavity. A circular opening with a diameter of 150 mm was then made at the bottom of the oven. Through the opening the microwave cavity was connected to an air heater and an axial air fan via a plastic duct. Two electrical heating coils with a total rated power of 2 kW were located inside the duct between the axial fan and the cavity. An axial air fan with nominal power of 0.25 kW was placed near the air inlet of the pipe. A metallic screen filter was fixed to the air inlet. To prevent leakage of microwave energy from the applicator, a perforated metallic plate was fitted to the circular opening. The diameter of each perforation was 5 mm. The extra function of the perforated plate was to have uniform air distribution.

A small hole was drilled on the top of microwave cavity through which the sample holder was connected to a strain gauge (load cell) located on the top of the oven. The sample holder comprised a Teflon frame with an attached fine mesh resin screen at the bottom. The sample holder designed was strong and heavy enough so that the stream of the air flow would not disturb the measurement of the sample weight. Inside cavity a Teflon guide pipe of $\varnothing$ 150×100 mm ($D \times H$) was fitted to the opening such that the air stream was directed to the base of sample holder. A microwave leakage detector (DJF-2000, Nankai, China) was used to insure there was no leakage through the openings and the perforations. As far as the requirement of the vapor outlet is concerned, the original outlet provided was adequate for the new setup to exhaust the vapor; no further modification work was done about the vapor outlet. Fig. 1 shows schematics of the microwave drying setup.

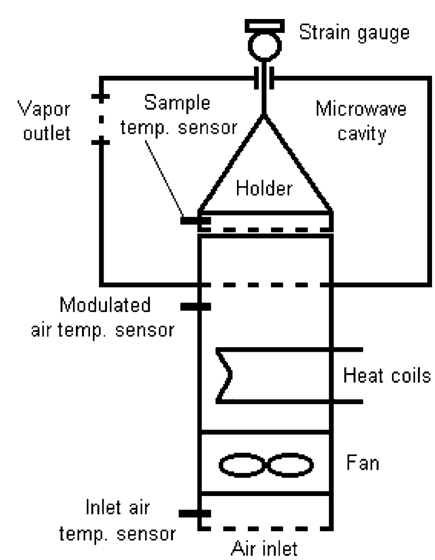

Fig. 1. Schematics of the microwave drying setup showing cavity, air heating and blowing system, sensors, and sample holder.