Microwave Drying System with High-Tech Phase Controller: A Modified Applicator

A. S. Jambhale, and B. V. Barbadekar

***Abstract*—**Microwave energy can be used for drying purpose. It is unique process. It is distinctly different from conventional drying process. It is advantageous over conventional drying / heating processes. When microwave energy is used for drying purpose, the process can be accelerated with a better control to achieve uniform heating, more conversion efficiency, selective drying and ultimately improved product quality of the output. Also, less floor space and compact system are the added advantages. Existing low power microwave drying system is to be modified with suitable applicator. Appropriate sensors are to be used to measure parameters like moisture, temperature, weight of sample. Suitable high tech controller is to be used to control microwave power continuously from minimum to maximum. Phase - controller, cycle - controller and PWM - controller are some of the advanced power control techniques. It has been proposed to work on turmeric using high-tech phase controller to control the microwave power conveniently. The drying of turmeric with microwave energy employing phase controller gives better results as formulated in this paper and hence new approach of processing turmeric will open future doors of profit making to allied industries and the farmers.

***Keywords*—**Applicator, microwave drying, phase controller.

I. Introduction

DRYING with Microwave Energy is distinctly different from conventional methods. Conventional methods depend upon the slow march of the heat from surface of the material to the interior as determined by a change in temperature from a hot outside to cool inside. Where as heating with dielectric and microwave drying is a sort of bulk heating in which electromagnetic field interact with the material as a whole. In microwave drying, the oscillating electric field causes polar molecules to rotate and charged ions to oscillate. This ionic and molecular movement with intermolecular friction causes rapid heating [5]. Heating takes place volumetrically and water is heated, vaporized within the whole volume of the food product. The rapidly formed water vapor creates a large pressure gradient, which is drying force in microwave drying [4].

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A. Advantages of Microwave Drying System

Microwave drying presents the following advantages over conventional thermal heating/drying methods [8]:

- ❖ Process speed is increased.
- ❖ Uniform heating may occur throughout the material.
- ❖ Energy conversion efficiency is more. In microwave drying system, energy couples directly to the material being heated. It is not wasted in heating the air, the wall of the oven, conveyor etc. This can lead to sufficient energy saving. Also the energy source is not hot and plant cooling saving may be realized.
- ❖ Better and more rapid process control occurs.
- ❖ Floor space requirements are less. It is due to more rapid heating by microwave energy.
- ❖ Selective drying may occur. The electromagnetic field generally couple in to the solvent and not the substrate. Hence it is the moisture which is heated; where as the carrier of the substrate is heated primarily by conduction. This avoids heating of the air, open walls, conveyor etc.
- ❖ Product quality may be improved. Since, high temperature is not usually generated, there is an elimination of the over heating of the surface and case hardening which are common with conventional heating method. This often leads to less rejected products.
- ❖ Desirable chemical and physical effects may result. Many chemical and physical reactions are promoted by the heat generated in this method, leading to the puffing, drying, melting, protein denaturation, starch gelatinization and the like.
- ❖ Microwave drying can be conveniently combined with other methods of drying, such as, hot air drying, freeze-drying, vacuum drying etc.

II. Drying Methods

A. Solar Drying

Solar drying has been used to dry fish, meat, cloth, grains and has proved to generate food stuffs of high quality and low spoilage, though, solar drying is cheap easy and popular method, its application is restricted by the long drying time and need for favorable weather. Tulsidas (1994) showed that 6-9 weeks were required to dry grapes to a water content of 25

– 30 % and further steps were required to dry them completely [10].

B. Hot Air Convective Drying

The principle of hot air convective drying is based on conventional heat transfer from heated air to the material being dried. Hot air is forced through the material and does the moisture diffusion process that result in the drying. This method has been widely used in industries. Different types of dryers have been developed and employed in commercial production [6] Heated air is blown through the material by cross flow or by fan generated flow. As compared to solar drying, hot air convective drying can greatly shorten the drying time from several weeks to several days. However, same studies have been reported that the taste, color and overall quality of dried berries could be improved by using alternative methods, such as microwave drying (Tulsidas, 1994).

C. Freeze- Drying

Some pharmaceuticals are heat sensitive. Some fruits and vegetables loose their aroma and flavor if they remain in high temperature for significant figure of time. For such cases freeze drying is an alternative. Freeze-drying was introduced on large scale in world war-II. It was used in production of dried plasma and blood products [1]. Freeze- drying requires several successive steps, as pre-freezing, primary drying, secondary drying, conditioning and dehydration. It is expensive and requires sophistication. Hence, it is difficult to apply to all commercial drying needs.

D. Vacuum Drying

There are four essential elements in a vacuum drying system: a vacuum chamber, vacuum generating device, system for collecting water vapor and means for supplying heat required for vaporization of water [3]. For reasons similar to freeze-drying vacuum drying is also an expensive drying method. It is used only for costly products.

E. Microwave Drying

Microwave Drying is not only faster but also requires less energy consumption than conventional drying (Tulsidas 1994). In the drying of osmotically pre-treated strawberries or blueberries, it has been showed that microwave drying required shorter drying time than freeze drying, while maintaining the same final product quality [11]. Also it has been reported that the use of microwaves in freeze-drying could substantially increase drying rate and consequently, decrease drying time (Sanga - 2000). It has been compared hot air-drying, freeze-drying, vacuum drying and a combination of hot air and microwave drying of cranberries [2]. It was concluded that microwave-assisted hot air drying resulted in the shortest drying time and acceptable color, taste and texture. Also it has been compared the microwave assisted vacuum-drying to microwave assisted hot air drying and concluded that the microwave assisted vacuum-drying offered a slight advantage in product quality and process efficiency [9]. It has been dried flowers with microwave energy in conjunction with a color- protecting treatment, which offered a number of advantages over conventional methods [7].

III. Material and Methods

A. Microwave Drying Applicator

Microwave drying applicator was developed / modified based on Samsung Microwave oven C103 FL with nominal power of 900 W at 2450 MHz as shown in Fig. 1.

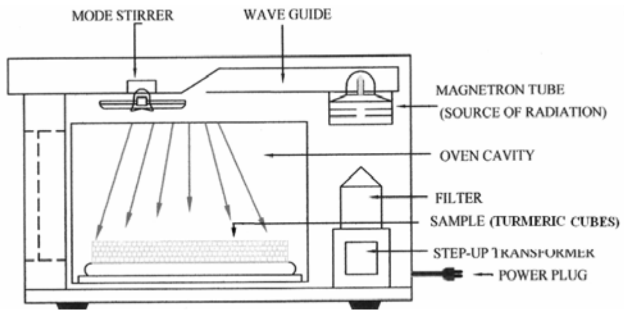

Fig. 1 Microwave oven Samsung C103 FL with sample (Courtesy Samsung)

Microwave oven Samsung C103 FL type has specification as follows-

Power source: 230V, 50 Hz
Microwave power: 1400Watt
Average maximum power: 900 Watt
Grill (heating element): 1300Watt
Convection (heating energy): 1700Watt
Operating frequency: 2540MHz
Outside Dimensions (WXDXH): 517x511x310 mm
Oven cavity: 336x347x253mm
Volume: 28 liters
Weight: 19Kg

The developmental work included-

- ❖ Development of microwave and convective drying system.
- ❖ Design of a triac phase controlled power regulator (phase – controller).
- ❖ Modification of original electrical circuit, as shown in Fig. 2.

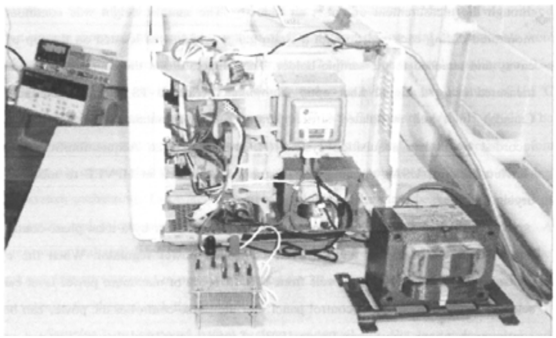

Fig. 2 Modified Electrical Circuit

The experimental set-up is as shown in Fig. 3

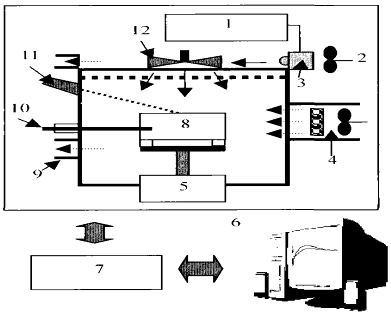

Fig. 3 Experimental set- up
1.Microwave power controller (phase-controller); 2. Cooling fan; 3. Magnetron; 4. Heater & blower; 5.Electronic Weighing balance; 6. Personal computer; 7. Data acquisition & control system; 8. Sample (Turmeric cubes); 9. Ventilation; 10. Thermocouple; 11. Infrared temperature sensor; 12. Microwave stirrer

The hot air was introduced into oven by electrical heater and the small air blower with average electric energy consumption of 1 KWh. Ventilated hot air was not recycled and there was no heat recovery from the exhausted air. Infrared temperature sensor and thermocouple (K-type) were used to measure the surface temperature and core temperature of turmeric cubes during drying respectively. Electronic weighing balance was attached to the tray on which the sample was placed to monitor the sample weight change during drying. All the sensors were monitored and saved by personal computer.

B. Sample Preparation

Samples were prepared before each experimental run. Turmeric rhizomes were pealed and cut into cubes of 10 x 10 x 10 mm. All sample cubes were taken from the centre medulla region of the rhizome tuber for a more uniform cell structure. The sample cubes were immediately soaked in tap water to prevent browning before all cubes were cut. Samples were evenly spaced and placed as a single layer on the base of the sample holder.

As a first step of each run, the data acquisition system was switched on. A sample of 500 gm was used for each run. Sample centre temperature was monitored. During each trial inlet air and modulated air temperature, sample weight and sample temperature were recorded continuously by the data acquisition system. The drying process was finished when the sample reached the moisture content of less than 10%.

IV. RESULTS

Tests were taken for dimensionless moisture content, drying rate during drying as g/min and temperature variation during drying process, both for phase and cycle controlled modes. Using a sample of 500 gm, observations were noted down as given in Table I and Table II and the graphs were plotted as shown in Figs. 4, 5, 6, 7, & 8.

TABLE I
MICROWAVE DRYING WITH CYCLE-CONTROLLED MODE

Sr. No.	Drying time (min)	Dimension-less moisture content	Drying rate (g/min)	Sample Temp. (^oC)
1	0	1	0.45	25
2	5	1	0.45	34
3	15	0.8	0.85	60
4	25	0.45	0.80	70
5	35	0.25	0.8	68
6	45	0.10	0.62	62
7	55	0.04	0.61	61
8	65	0.02	0.02	61
9	75	0.01	0.0	61
10	85	0.025	0.0	61
11	95	0.0	0.0	61
12	105	0.0	0.0	61

TABLE II
MICROWAVE DRYING WITH PHASE-CONTROLLED MODE

Sr. No.	Drying time (min)	Dimension-less moisture content	Drying rate (g/min)	Sample Temp. (^oC)
1	0	1.0	0.3	25
2	5	1.0	0.3	34
3	15	0.8	0.62	42
4	25	0.615	0.6	50
5	35	0.42	0.605	57
6	45	0.25	0.6	59.5
7	55	0.10	0.55	60
8	65	0.02	0.15	61
9	75	0.015	0.1	61
10	85	0.005	0.0	61
11	95	0.0	0.0	60.5
12	105	0.0	0.0	---

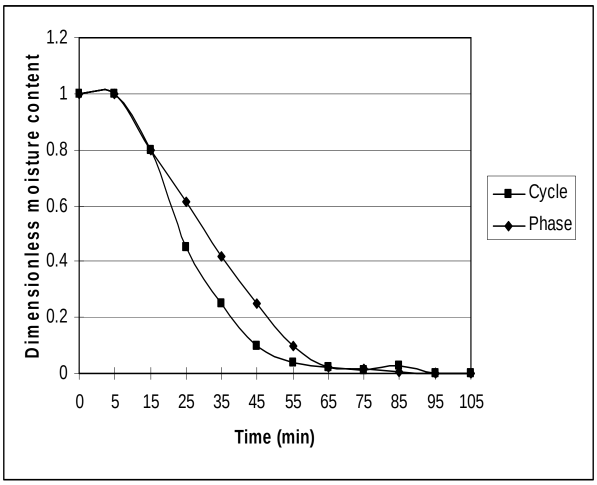

Fig. 4 Dimensionless moisture content Vs Time (min)

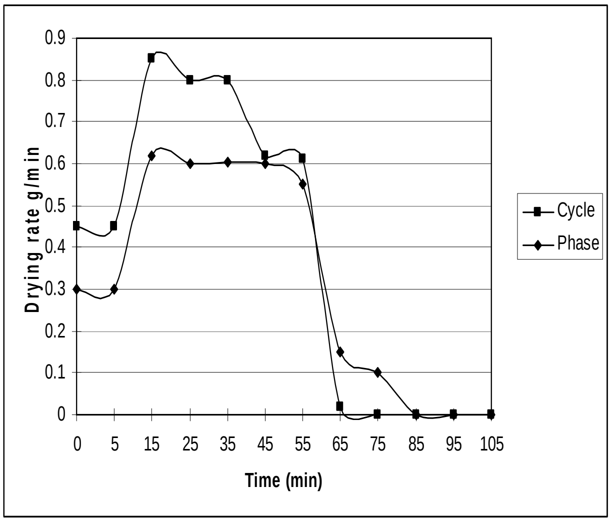

Fig. 5 Drying rate (g/min) Vs Time (min)

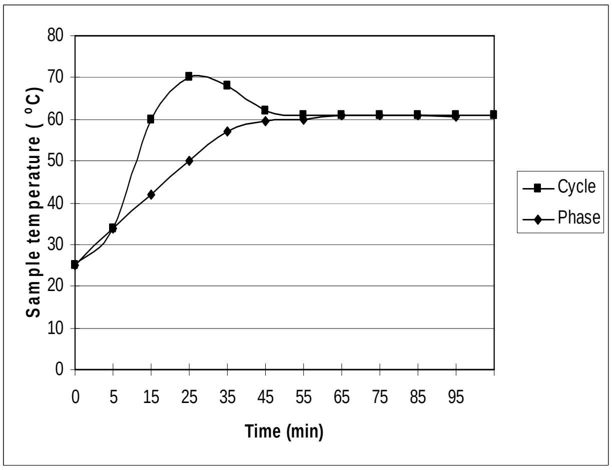

Fig. 6 Temperature variation (^{0}C) Vs Time (min)

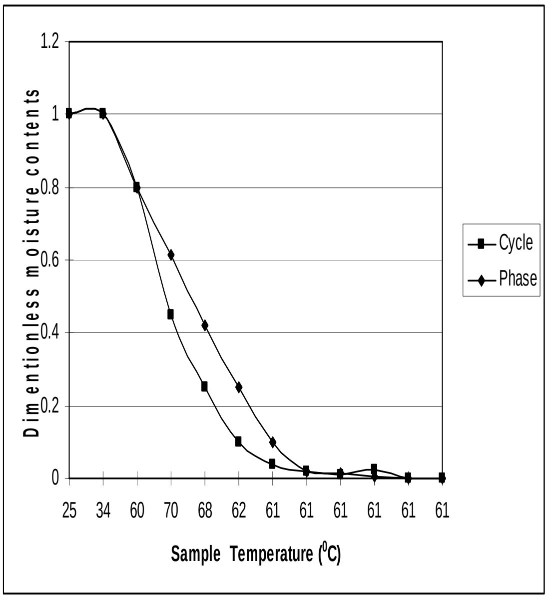

Fig. 7 Dimensionless moisture content Vs Sample Temperature (^{0}C)

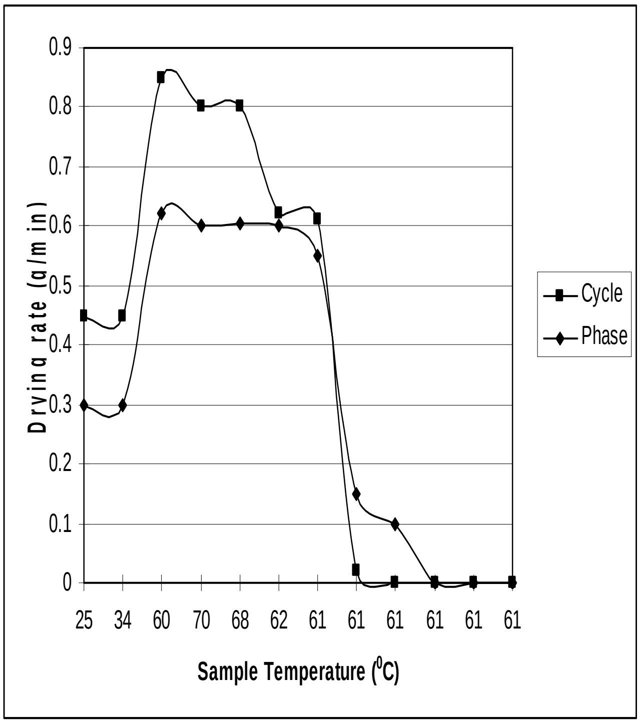

Fig. 8 Drying rate (g/min) Vs Sample Temperature (^{0}C)

Higher drying rate is obtained during cycle controlled microwave applicator process as compared to phase controlled microwave applicator drying process. The temperature curve during cycle controlled microwave applicator drying could be roughly spited into three different zones. In first zone the temperature rose, first sharply and then gradually, to reach a peak value and then decreased to constant temperature.

The material temperature dropped slowly after reaching maximum value followed by a steady temperature period. As shown in drying rate curves, the first and second temperature zones correspond to the constant drying rate region where most moisture loss occurred. Two distinct zones were observed in temperature curve. During phase-controlled mode a gradual temperature rising zone followed by a stable temperature zone, the zone nearly matches the constant drying region. Where as, during cycle-controlled mode there is fast increase in temperature above stable zone, then it decreases slightly and comes to stable temperature zone. Plots for drying time and drying temperature Vs drying rate & dimensionless moisture content respectively are identical.

V. Conclusion

During microwave drying of turmeric cubes, the drying rate of cycle-controlled drying is faster / higher than phase-controlled drying.

- ❖ More accurate temperature control could be realized using phase-controlled mode compared to cycle controlled mode.
- ❖ In both the drying modes, the drying time increases with decrease in microwave power.

- ❖ The product color and sensory attributes were not affected by power controlled method.
- ❖ Process resulted as uniform heating and drying.

ACKNOWLEDGMENT

The authors thank their colleagues from College of Engineering, Malegaon (Bk) Baramati for encouraging publishing the paper & University of Pune for the financial support for the project.

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