Development of Far Infrared Ray Dryer for Agricultural Products

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ABSTRACT

A Far Infrared Ray(FIR) dryer was designed, constructed and tested for red pepper, lycium chinese, and mushroom(Cortiellus shiitake) drying, and the results were compared to the heated air dryer at the same condition. In the FIR dryer, three different panel materials, galvanized, copper and stainless steel, were used and no ceramic coating and those with cereamic coating(three panels) were 58%, 56%, 64%, and 88%, respectively. The drying times of lycium chinese and mushroom were shortened in FIR dryer by 6 hrs and 4 hrs compared to the heated air drying, respectively, while no remarkable difference in the drying times was found in the red pepper drying. The quality of products was better in FIR dryer where more red color value for red pepper and lycium chinese and more brightness for mushroom. The drying performance of a FIR dryer was superior in terms of total cost of 80,800 WON/100kg of lycium chinese, reduced by 25% compared to the heated air drying.

Key words : Far infrared ray dryer, Heated air dryer, Drying, Ceramic coating

Introduction

With the economic growth in korea consumers' food consumption pattern was diversified and quality-oriented. Most of agricultural production process were mechanized, from seeding to harvest, however, postharvest processes are conducted by manual or traditional methods which incurs economic loss to farmers. For drying process itself, the economic loss by unappropriate method is 20 to 40%. FIR application was introduced to refrigenerator manufacturing and car painting long times ago, but in agricultural drying process it is relatively new field.

Up to this time, drying methods are natural air drying or heated air drying and for some high value agricultural products vacuum drying and vacuum freeze drying are using in addition to FIR and high frequency drying method. FIR is defined as long wave infrared ray, a range of 5.6 to 1000㎛ of which a range of 2.5 to 10㎛ is using in the drying of agricultural products. Though we can expect the cost of FIR drying would be less than vacuum and vacuum freeze drying and to get high quality product than heated air drying, however, we don't have enough information on the drying characteristics and advantages over other drying methods. So, this study of FIR drying was initiated in order to investigate the drying characteristics, drying quality and drying energy for mushroom, red pepper and lycium chinese drying, and the results were compared to heated air drying.

Methods and Materials

Prototype emission panel

Fig. 1 shows the plain view of the emission panel. Three different perforated panels were prepared, galvanized, copper, stainless steel, and two treatments, ceramic paint (SM17) and no paint, were applied, where the hole ratio was 50% for easy air ventilation. Emissivity was measured by emissivity meter of BIORAD FT40 working on temperature range of 40~500℃ where the emissivity range was 4 to 10㎛ for easy water absorbing zone.

Drying apparatus

Fig. 2 shows the prototype FIR dryer consisted by three parts : drying, heating, control part. The drying part is composed of drying trays made of alumina wire net and emission panels. The distance between panels was 120mm considering the emission efficiency and the number of tray bed was 10. Temperature in the drying chamber and boiler and air circulation and exhaust fan were controlled by the control part. Ventilation fan was operated every 10 minutes. Table 1 shows the specification of prototype dryer.

Test materials and drying methods

The drying materials were mushroom, red pepper and lycium chinese produced in 1995 and stored in the environment chamber till the test begins. Two drying methods, heated air drying and FIR drying, were employed in this trial. The drying temperatures of red pepper and lycium chinese were set on 55, 65, 70℃, for mushroom 45, 55, 60℃, and initial weight of the test materials was in the range of 450 to 550g.

Moisture content measurement and products quality assessment

Moisture content was calculated by the weight differences of the sample material during the drying time. In order to estimate the weight differences, strain gauge was attached to a cantilever beam where a sample tray placed on and the strains were transferred to the data acquisition system composed of UCAM, PC, data recorder and printer. Dried products quality was assessed by the product surface color, where Lab values and the magnitudes of Lab values were compared before and after the drying process. For red pepper and lycium chinese quality was judged by the magnitude of red color value, for mushroom by that of white color value. Product color measurements were conducted on the five samples by CHROMOMETER(CT2000).

Results and Discussions

Emissivities of the emission panels

At 100℃ and wave length of 4~25μm, emissivities of the three different panel materials are shown in Fig. 4. Emissivities of the no treatments were 58, 56, 64%, however, with ceramic coating treated panels it was in the range of 87 to 89% regardless of panel materials.

Drying characteristics curve

Lycium chinese

Drying characteristics for lycium chinese are shown in Fig. 5 where constant rate period of drying appeared in the initial drying stage and falling rate period of drying was shown after 6 hours in the FIR drying, but no falling rate period in the heated air drying. It appeared that heat transmission effect caused by radiation heat transfer in the FIR drying was greater than that of heated air drying.

Red pepper

Drying characteristics curves for red pepper are shown in Fig. 6 where constant rate period of drying was appeared in the initial drying stage and falling rate period of drying was shown in the time period of 8 to 12 hours in the both dryings, then constant rate period of drying was shown. Though drying velocity was slower in the heated air drying, but no difference in the curve shapes.

Mushroom

Drying characteristics curves for mushroom are shown in Fig. 7. No difference was found in the two dryings, however, because of mushroom's deep flesh falling rate period of drying appeared in the later stage.

Products quality

Table 2 shows Lab values of the products in the different treatments. For red pepper the red color value (L*a) was 457, the highest, in the FIR drying of 55℃, which was much higher than the heated air drying at the same condition, by 146. The same trends were found in the lycium chinese and mushroom drying maintaining original color and high quality product.

Drying energy

Energy indexes were calculated based on the each product at one temperature and tabulated in the Table 3, which indicated that more energy was consumed in the heated air drying than FIR drying. Energy savings in the red pepper and lycium chinese at 65 ℃ were 20% and 25%, respectively, and for mushroom 7% energy saving at 55℃.

Cost analysis of the FIR and heated air drying

Drying costs for 100kg of dried product on the heatd air and FIR drying were for red pepper 106,964 and 80,800 WON, for lycium chinese 126,412 and 121,200 WON and for mushroom 97,240 and 80,800 WON. It showed that FIR dryings of red pepper, lycium and mushroom were cheaper than heated air drying by 25, 5, 17% in the total cost.

Conclusions

The study for the different drying methods, FIR and heated air drying, with lycium chinese, red pepper and mushroom, following results were drawn.

1. On the emissivity measurement, some difference was found in the three panel materials , galvanized, copper and stainless steel panel, with no ceramic coating, but no difference was in the three materials with ceramic coating. And, the emissivity difference was 30% or more between the coated and no coated panel.

2. In the drying time comparison, about three hours, was taken in the drying of red pepper in the FIR and heated air drying, however, for lyciun chinese drying at 65℃ it was 23 hours in the FIR drying, 6 hours shorter than heated air drying reduced by

22% in terms of drying time, and for mushroom drying at 55℃, it was 16 hours by FIR drying saving 4 hours, as 22% drying time reduction.

3. On the dried products quality assessments, red color value (L*a) measured by CHROMOMETER at 55℃ for red pepper drying with FIR dryer was the highest, 457, greater than 311 of heated air drying by 147, the same trend appeared in the lycium chinese drying. It indicated that FIR drying would be better drying method than heated air drying.

4. FIR drying saved drying energy by 33%, the largest, in the drying of lycium chinese at temperature of 65℃ compared to the heated air drying.

5. Total cost for lycium chinese drying, 80,800 WON/100kg, was saved by 25% in the FIR drying compared to the heated air drying of 106,964 WON/100kg.

6. Based on the information collected in this study it appeared that FIR drying is superior to heated air drying considering the drying time, products quality and energy consumption index, where the proper drying temperature was 65, 65 and 55℃ for lycium chinese, red pepper and mushroom, respectively.

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Table 1. Specification of prototype

	Items	Specification
Main body	Size(LXWXH)	1,000 X 1,000 X 2,000mm
	Circulation fan	Control by timer
	Ventilation fan(ps)	1/4
Drying part	Size of drying room(LXWXH)	730 X 900 X 1,500mm
	Size of tray(LXWXH)	680 X 900 X 40mm
	Number of tray	10
	Hole ratio of tray(%)	50
	Radiation direction	Up and down
Heating part	Capacity of boiler(kcal/hr)	12,000kcal/hr
	Fuel	LPG
	Heating medium	Water(25 ℓ)

Table 2. Products' Lab values of the different treatments.

Kind of crop		Before drying	Far infrared ray drying			Heated air drying			Natural drying
			55℃	65℃	70℃	55℃	65℃	70℃	
Red pepper	L	36.6	**32.9**	25.7	30.0	**330.8**	27.2	32.2	40.2
	a	33.9	**13.9**	10.2	11.2	**10.1**	4.8	9.0	26.0
	b	12.9	**4.6**	4.2	4.4	**3.1**	2.4	3.8	8.1
Lycium chinese	L	37.2	35.5	36.4	30.5	29.0	26.5	24.5	28.0
	a	24.6	12.4	10.6	10.4	8.4	11.6	8.9	11.1
	b	14.6	6.9	5.4	6.4	5.5	8.9	7.2	15.0
Mush-room	L	50.9	42.1	24.9	48.3	39.7	42.1	45.8	36.1
	a	6.5	6.2	5.6	5.3	8.5	6.1	7.0	4.9
	b	14.3	16.8	10.8	16.9	11.5	12.2	14.3	8.1

(L : White, a : Red, b : Yellow)

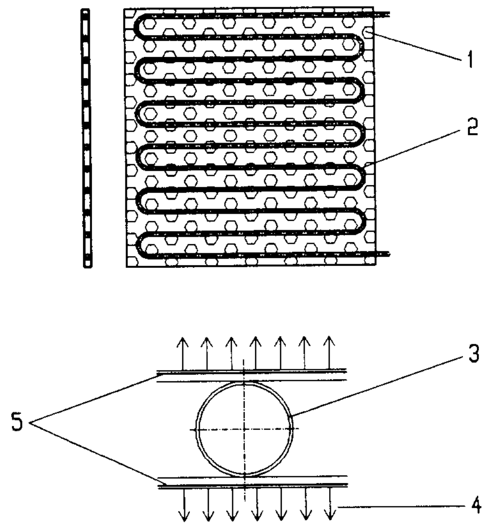
Table 3. Comparison of energy consumption between far infrared ray drying and heated air drying.

Samples	Far infrared ray drying			Heated air drying		
	55℃	65℃	70℃	55℃	65℃	70℃
Red pepper	**100**	103	115	158	128	132
Lycium chinese	160	**100**	111	180	**133**	143
Mushroom	123	**100**	105	126	107	115

Table 4. Cost analysis in the two drying methods.

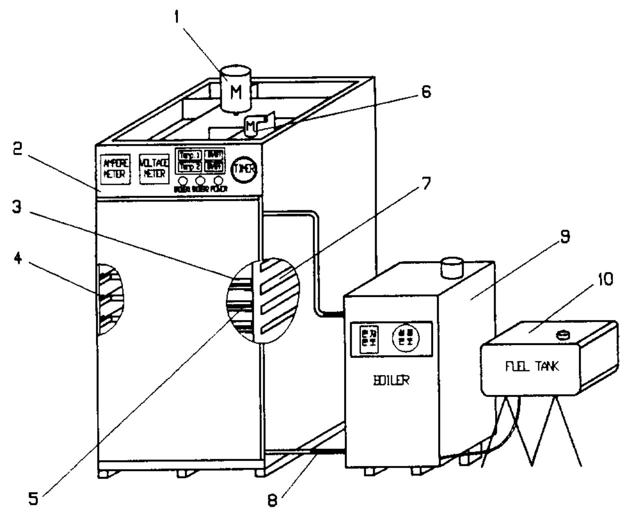
Items		Far infrared ray drying	Heated air drying
Purchasing price (won)		3,500,000	2,172,000
Service life (year)		8	8
Annual use (hr)		600	600
Fixed cost (won/hr)		1,108	688
Variable cost (won/hr)		3,942	4,174
Sub total cost (won/hr)		5,050	4,862
Drying performance (hr/100kg)	Red pepper	24	26
	Lycium chinese	16	22
	Mushroom	16	20
Total cost (won/100kg)	Red pepper	121,200(96)	126,412(100)
	Lycium chinese	**80,800(75)**	**106,964(100)**
	Mushroom	80,800(83)	97,240(100)

※Note 1. Wages : 31,074won/day for man
2. Annual repair rate : 5%
3. Annual interest : 5%
4. Farm electricity cost : 30.32won/kwh
5. Fuel cost : Heavy oil : 218won/ℓ



1,5 Emission panel
2,3 Stainless steel pipe
4 Emission arrow of far infrared ray

Fig. 1. Schematic diagram of far infrared ray emission



1. Ciculation fan
2. Control box
3. Drying tray
4. Fluid control valve
5. Emission panel
6. Ventilation fan
7. Air flow hole
8. Stainless steel pipe
9. Boiler
10. Fuel tank

Fig. 2. Schematic diagram of prototype.

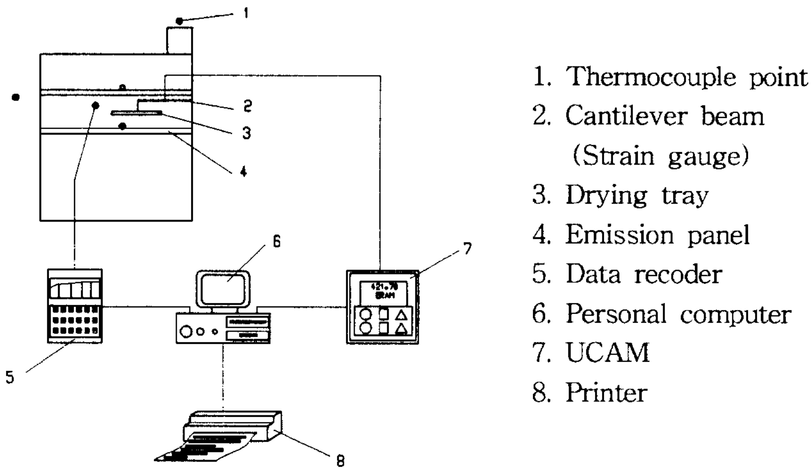


Fig. 3. Schematic diagram of apparatus of drying rate measurement.

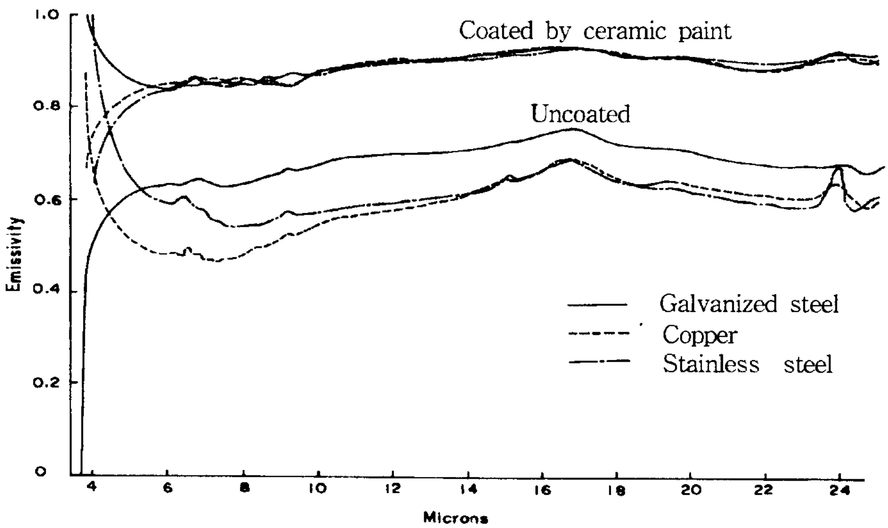


Fig. 4. FIR emissivities of the six different treatments.

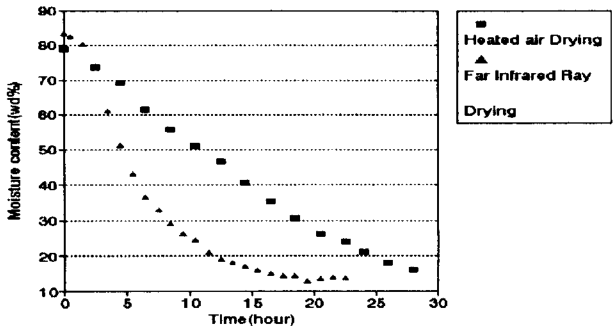


Fig. 5. Relationship between moisture content and drying time at 65℃ for the lycium chinese.

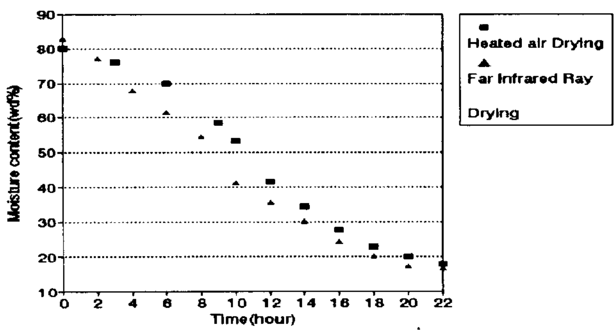


Fig. 6. Relationship between moisture content and drying time at 65℃ for the red pepper.

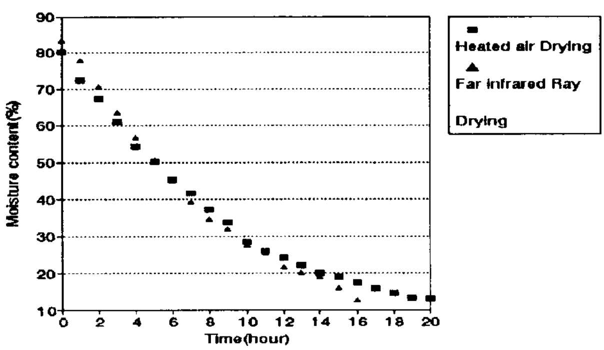


Fig. 7. Relationship between moisture content and drying time at 55℃ for the mushroom.