The Integrated Method for Drying Agricultural Products.

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Abstract**—** The preservation of agricultural products is the most important issue in order to prolong the shelf life of products on the market. One of the commonly used methods is the application of hot air drying directly to products. Another method is the utilization of infrared tube as the source of heat transmission. Both methods have pros and cons. As a result, this research focuses on the integration of these two methods in order to fulfill the gap of each individual method. To validate the efficiency of the proposed method, the experiments are conducted to measure the moisture content of two agricultural products, tomatoes and pineapples. The results show that the integrated method is able to decrease more moisture content of products than two traditional methods.

Keywords**—** Drying, Heating Infrared, Hot Air, Integration, Moisture Content.

I. Introduction

Heat Pump is a heating method concerning the movement of heat from source to another area which is called sink. As a result, it is one of the methods always used for drying process. The advantages of heat pump technique are the energy usage efficiency and the capability to control the heat for different profiles of products. However, the down side is the issue regarding pressure control. On the other hand, infrared heating or heat lamp is a device which radiates heat through electromagnetic wave. Therefore, there is no need for the medium (the operation is possible both in the vacuum and normal atmosphere environment). Another advantage is the capability to transfer heat very rapidly. As a result, the popularity for the application of heating infrared for drying process is growing exponentially. On the contrary, the problem is the capital cost of equipment is still high when it is compared with those of traditional convection methods..

II. Math

Drying process is important for the preservation stage of agricultural products, e.g., fruits and vegetables. However, there are many concerns regarding the quality degradation, e.g., color loss [1], change in texture of products and loss of nutrients [2]. Moreover, the excessive temperature from the drying process also leads to the quality issue of products. For drying technique, heat pump is widely used for drying purpose of agricultural products [3]. The study of this method is at its peak in the 1950s and it is proved to be mechanically feasible. Normally, convectional drying method concerns with the transfer of heat (hot air) from source to the target. However, there is a high amount of heat loss in the process. As a result, heat pump technique was introduced to recover the lost energy and return it back to the system. Since the thermal conductivity of food products is low, the heat transfer rate is low. The utilization of heat radiation method was introduced to improve the heat transfer capability. A heat radiation method, infrared heating, is the application of infrared wave with a wavelength of 0.75 to 1000 μm. Sandu [4] has reported that the infrared wave is able to transmit the energy efficiently to the targets. Hebbar et al. [5] combined two heating techniques, heat pump and infrared heating, together to dry vegetables. The application of drying process is shown in the research works by Shahari and Hibberd [6], Fudholi et al. [7] and Ibrahim et al. [8]. As a result, two most popular techniques, hot air and infrared heating, are combined in order to bring out the best from these two methods.

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III. Hardware Development

For the generation of hot air, the amount of power consumption is 2700 W while the voltage used is 220 Volt. As shown in Table 1, the capacity of the chamber is 540*425*390 mm and there are four trays available. The maximum weight of a device is 70 kg while the maximum heat temperature able to be produced is 300 Celsius degree. The front side of a device is shown in Fig.1 while the control panel of a device is illustrated in Fig.2. The panel is categorized into two modes, analog panel for hot air control and digital one for infrared heating.

Table 1. Characteristic of hot air production unit.

Characteristic	Unit
Electrical inlet	220 Volt
Power consumption	2700 Watt
Number of tray	4
Tray size	370*550 mm.
Dimension	540*425*390 mm.
Weight	70 kg.
Maximum temperature	300 Celsius degree

On the contrary, infrared heater works on the basis of heat radiation which is totally different from heat convection. For heat convection, once the surface area is heated and the heat is gradually absorbed inside the object. Thus, the object is thoroughly heated and the time used is ten times less than that of heat convection. Moreover, it can save as much as 30-50% of energy. For this research, the emitter type of infrared radiator is a ceramic tube which emits the infrared ray at the wavelength of more than 4 μm. This range of wavelength is suitable for drying agricultural products, e.g., fruits and grains. The efficiency of radiation (percentage of emissivity) is between 30 and 50 percent while the maximum radiant source temperature is 550 Celsius degree (Table 2). Moreover, the amount of energy consumed is 700 Watt and the voltage used is 220 Volt (which is common in Thailand and mot South-east Asian countries). As shown in Figure 3, the infrared heating tube was installed on the top of the chamber for the optimal radiation of heat.

Fig. 1 Front side.

Fig.2 Control Panel.

Table 2. Characteristic of infrared heating tube.

Characteristic	
Shape	-Tube -Length: 500 mm. -Circumference: 17 mm.
Material	Ceramic
Wavelength	>4μm
Emissivity	30-50%
Maximum radiant source temperature	550 Celsius degree
Electrical inlet	220 Volt
Power consumption	700 Watt

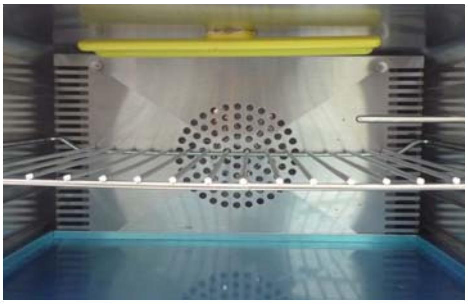

Fig.3 Infrared heating tube.

IV. Results

The efficiency of the newly designed device is measured by considering the moisture content inside the heated object before and after the heating. The experiment was conducted to assess the performance of the innovative device compared to the traditional ones. Therefore, there are three treatments,

-Hot air

-Heating infrared

-Combination method between hot air and heating infrared.

The test objects are differentiated into two cases. The first one is tomatoes and the second one is pineapple. The size and moisture of the test object before the experiment is the same. Moreover, the period of time used to heat each object is equal.

A. Tomatoes

The tested objects are tomatoes which have the average moisture content of 94 percent. After the heating by three methods, the experimental design and the results are shown in Table 3 and Table 4 consecutively. Due to Table 3 and Table 4, each treatment has 10 replicates. Afterwards, the analysis of variance (ANOVA) is utilized in order to test statistically whether there is any significance among these treatments.

Table 3. Experimental design and results.

Treatment	Replicate				
	1	2	3	4	5
Hot air	62	63	63	64	61
Heating infrared	61	65	63	66	60
Combined	43	42	41	42	44

Table 4. Experimental design and results (Cont).

Treatment	Replicate				
	6	7	8	9	10
Hot air	62	63	64	65	62
Heating infrared	62	64	64	66	61
Combined	43	44	45	41	42

Table 5. Descriptive statistics.

Groups	Count	Sum	Average	Variance
Hot air	10	629	62.9	1.433333
Heating infrared	10	632	63.2	4.622222
Combined	10	427	42.7	1.788889

Table 6. ANOVA results.

SOV	SS	df	MS	F	P-value
Between Groups	2761.267	2	1380.633	528.0042	2.27E-22
Within Groups	70.6	27	2.614815		
Total	2831.867	29			

Table 7. t-test for mean from hot air and combined method.

Statistics	Hot air	Combined
Mean	62.9	42.7
Variance	1.433333333	1.7888888
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	35.5855453	
P(T<=t) one-tail	1.94698E-18	
t Critical one-tail	1.734063592	
P(T<=t) two-tail	3.89396E-18	
t Critical two-tail	2.100922037	

Table 8. t-test for means from heating infrared and combined method.

Statistics	Heat. Infrared	Combined
Mean	63.2	42.7
Variance	4.622222222	1.7888888
Observations	10	10
Hypothesized Mean Difference	0	
df	15	
t Stat	25.602785	
P(T<=t) one-tail	4.29183E-14	
t Critical one-tail	1.753050325	
P(T<=t) two-tail	8.58366E-14	
t Critical two-tail	2.131449536	

B. *Pineapples*

Another experiment is conducted on another type of fruit, pineapples. The experimental results are shown in Table 9-12.

Table 9. Experimental design and results.

Treatment	Replicate				
	1	2	3	4	5
Hot air	53	52	51	50	49
Heating infrared	50	51	53	52	50
Combined	38	36	35	36	36

Table 10. Experimental design and results (Cont).

Treatment	Replicate				
	6	7	8	9	10
Hot air	51	52	54	55	52
Heating infrared	51	50	49	51	50
Combined	37	35	34	35	36

Table 11. t-test for mean from hot air and combined method.

Statistics	Hot air	Combined
Mean	51.9	35.8
Variance	3.211111	1.288889
Observations	10	10
Hypothesized Mean Difference	0	
df	15	
t Stat	24.00046	
P(T<=t) one-tail	1.11E-13	
t Critical one-tail	1.75305	
P(T<=t) two-tail	2.21E-13	
t Critical two-tail	2.13145	

Table 12. t-test for means from heating infrared and combined method.

	Heat Infrared	Combined
Mean	50.7	35.8
Variance	1.344444	1.288889
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	29.03577	
P(T<=t) one-tail	7.14E-17	
t Critical one-tail	1.734064	
P(T<=t) two-tail	1.43E-16	
t Critical two-tail	2.100922	

According to the experiment, it is obviously shown that the mean of moisture content of the fruits after using the combined method is significantly lower than the ones using hot air of infrared method alone.

V. Conclusions

According to the results, the utilization of hybrid methods, hot air and infrared heating, is better than the application of each method alone. The performance index is the moisture content in the products after the application of heat to the agricultural products. The results indicate that the hybrid can effectively remove the moisture from specimen products.

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