



The Construction and Testing of a Combined Solar and Mechanical Cabinet Dryer

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Abstract

The combined solar and mechanical dryer was constructed to use solar energy and electrical energy either separately or in combination to conduct air drying. There was various arrangement of drying condition for mechanical drying system such as using either 1KH-1F or 1KH-2F or 2KH-1F or 2KH-2F. While for solar drying either no fan or one fan or two fans were used. Different drying conditions were applied by changing the heating source and flow of air. The highest temperature was obtained in 2KH-1F condition for mechanical drying and convection gives highest temperature among different solar drying alternatives. The temperature in upper shelf for different solar operational condition ranged from 1.53 to 1.67 times of ambient temperature (25⁰C-31⁰C) at peak time and 1.28 to 1.36 for lower shelf. The air velocity was 0.35 m/sec and 0.70 m/sec for 1-fan and 2-fan respectively.

The performance of dryer was evaluated by drying potato slices having thickness 3, 5 and 7 mm. In both methods, drying rate increases with the increasing temperature and decreases with the increasing slice thickness following the power law equation. The values for the index 'n' of the power law equation are less than 2 (range from 0.53 to 1.42) for all the conditions, this indicating that external resistance to mass transfer was significant and internal resistance to mass transfer did not control the drying process under the given conditions. The effect of temperature on Diffusion co-efficient (D_c) follows Arrhenius type relationship. While analyzing the effect of temperature, the maximum activation energy for diffusion of water from Potato (7 mm thick slices, at upper shelf) was found to be 7.656 Kcal/g-mole and 8.252Kcal/g-mole for mechanical and solar conditions respectively.

Key Words: Solar, Mechanical, Dryer, Potato.

Introduction

Most of the modern preservation methods require high initial costs for installation of sophisticated machineries and equipments, skilled manpower and large capital investment for modern food processing industries. But the marginal farmers who are producing the perishable food items always expect low cost technology for preserving their produced items. Drying is one of the oldest and most widely used methods of food preservation (Guilani and Fung, 1986) and its success largely depends on the reconstitution properties of the dried products. Drying or dehydration refers the removal of moisture so that an unfavorable environment is created for microorganisms those normally cause spoilage (Hall, 1957). The dried products will be acceptable for food uses only if it retains good color, flavor, texture and nutritive value when water is added back to it. So the condition of drying and reconstitution procedures must be selected carefully. A thorough understanding of drying process and characteristics of raw materials are necessary for drier design and optimization (Bertin and Blazquez, 1986). The researchers are interested in product quality improvement and energy saving. Energy saving can be achieved by dryer/drying optimization and/or use of solar energy. One of the most common ways of drying is using air as a drying agent. Heat and mass transfer between air and the solid take place in opposite directions. One way of saving energy in this drying process is to

decrease the air flow in the drier. This is beneficial in two different ways; the first is the saving in energy (and investment) needed to circulate air and the second is a decrease in the air heating requirements (Mulet *et al.*, 1987).

Air drying of food can be accomplished by using mechanical drier, solar dryer or in direct sunlight. In mechanical dryer, temperature and air velocity could be controlled as compared to sun drying. This leads to higher production rates and high quality products due to shorter drying time and reduction of the risk of insect infestation and microbial spoilage. Since mechanical drying is not dependent on sunlight, drying can be performed whenever necessary. Traditional sun drying takes place by exposing the product under direct sun light with consequent loss in product quality due to radiation, dust, animal, insects, microbes etc (Karathanos and Belessiotis, 1995). Various forms of sun drying however, have the advantages of small or negligible installation and energy costs, though the running cost is high (as sun drying being a slow process due to climatic variation, is a labor intensive operation). In order to obtain good quality product an alternative to sun drying is solar drying or combined solar and mechanical drying utilizing renewable energy as much as possible. (Njie and Rumsey, 1997) pointed out that the drying is most significantly affected by the temperature followed by air velocity and radiation when sample

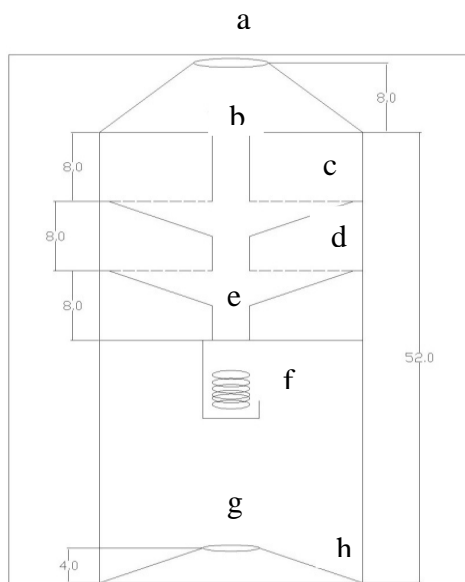
thickness is constant. Some dryers are coupled to solar collector to increase inlet temperature and consequently reduce relative humidity (Selkuc *et al.*, 1974 and Eissen *et al.*, 1985).

The overall objectives of the research work were (1) To construct a combined solar and mechanical cabinet dryer; (2) To evaluate the performance of

dryer and (3) Drying of potato with the constructed dryer.

Materials and Methods

The study was conducted in the laboratory of the Department of Food Technology & Rural Industries, Bangladesh Agricultural University, Mymensingh – 2202.



Legends

- a: Air out let
- b: Duct head
- c: Upper-shelf
- d: Lower-shelf
- e: Duct
- f: Heater and fan
- g: Air inlet
- h: Collector surface

Fig.1. Schematic diagram of the combined solar and mechanical dryer

Description of dryer

During mechanical drying, the electrical heater attached with fan was used. There were several arrangements of heater and fan such as 1KW heater and 1 Fan (1KH-1F), 1KW heater and 2 Fan (1KH-2F), 2KW heater and 1 Fan (2KH-1F), 2KW heater and 2 Fan (2KH-2F). This various arrangement provides various temperature with the variation in upper shelf and lower shelf temperature. And for solar drying, the surrounding air comes in to the air heating chamber and becomes hot as it collects heat from black collector as well as from direct sunlight. The heated air passes through the duct as a result of density variation. For the combined mode, both the solar and mechanical arrangement runs together providing heated air for air drying.

Drying of potato

For both the solar and mechanical drying, the potato slices of different thickness (3mm, 5mm and 7mm) were placed on each shelf in single layer and hot air passed through the shelf and the product was dried for 5 consecutive hours. The weight of slices was noted at a regular interval of 1 hr and from the known initial moisture content, moisture content at any time interval was calculated. To investigate influence of

temperature on drying rate at constant air velocity, sample with constant thickness was dried at variable temperature using various fan-heater combinations.

Analysis of experimental data

Experimental data was analyzed considering recommendations and relationships provided by several researchers (Jason, 1958; Saravacos and Charm, 1962; Salsa and Labuaza, 1968; Islam and Flink 1982a, b) using Fick's second law of diffusion for describing mass transfer during the first falling rate period of drying of food. And when drying occurs from one major face, the solution for an infinite slab with defined thickness was given by Brooker *et al.*, (1974); Crank, (1975) and Islam, (1980). Heldman, (1974) and Islam, (1980) shows that diffusion co-efficient has an Arrhenius type of relationship (exponential) with inverse air dry bulb temperature (absolute). The value of index of the power law equation (n) describing the relationship between rate constant and thickness should be 2 as the diffusion equation has been developed assuming simultaneous heat and mass transfer and external resistance to mass transfer are negligible. But "n" value as experimentally determined is generally found to be less than 2 (Alzamora *et al.* 1978; Islam,

1980) as the above conditions may not always be satisfied.

Results and Discussion

Velocity profile

It was seen that the velocity of air was uniform for both the operating system (1fan & 2fan) throughout the drying process. The uniform velocity was obtained within few second after starting the fan. The velocity of air for 1-fan operational system was 0.35 m/sec. and 0.70 m/sec. for 2fan operational system as recorded by an Anemometer.

Solar operation

The temperature was higher in the upper shelf than the lower shelf at the same day time for different

operational condition due to direct sunlight and flow of more hot air. The peak temperature was obtained in both shelves at 12pm. The more effective range of drying time for solar drying was from 11am to 1pm due to more intense radiation (Fig: 2). The temperature in upper shelf for different operational condition ranged from 1.53to1.67 (from fig: 2) times of ambient temperature at peak time and the range was 1.28 to1.36 for lower shelf. In both shelves the natural convection (without fan) provides higher temperature at different period due to lower air velocity. Two fan gives lower temperature than one fan in both upper and lower shelf due to higher velocity as per well-known heat transfer equation ($q=ms\Delta t$) (Heldman, 1974).

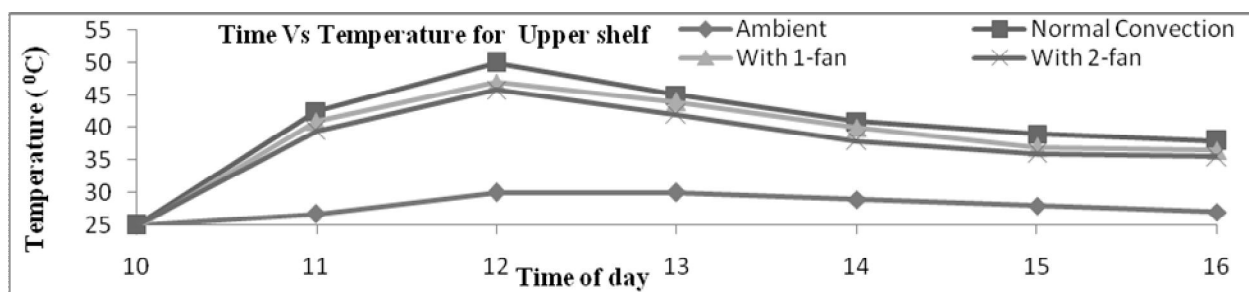


Figure 2. Temperature profile for solar system at different operating condition

Temperature conditions in the dryer as affected by heater-fan combination

From Table-1 it was observed that temperature was higher in the upper shelf than the lower shelf with the same configuration. The temperature in upper shelf ranged from 47°C to 70°C for different heater-fan configuration. The highest temperature was achieved in the upper shelf by 2KH-1F (70°C) and was successively followed by 2KH-2F (60°C), 1KH-1F (56.7°C) and 1KH-2F (47°C). The temperature in lower shelf ranged from 42°C to 50°C for different operational conditions and the sequence was same as the upper shelf with respect to temperature with the exception that 1KH-1F and 2KH-2F gave similar temperature (47°C). The highest temperature (50°C) was given by 2KH-1F, while the lowest temperature (42°C) was given by 1KH-2F, while 47°C was given by either 2KH-2F or 1KH-1F.

Drying of potato

An experiment using either 2KH-1F or 1KH-1F and variable sample thickness (3,5 and 7 mm) was conducted to investigate influence of the parameters on drying time. It was seen (Table 2) that for a given heater-Fan configuration drying time was the lowest for 3 mm slices followed by 5 mm slices while the highest drying time was required for 7 mm slices to a certain level of moisture content (dry weight basis, db). It was also noted that for a constant thickness 2KH-1F gives the lowest moisture content for a given drying time i.e drying is faster in 2KH-1F configuration to 1KH-1F combination. And lowest drying time observed for 3 mm slices compared with 5 mm or 7 mm for a given heater-Fan configuration is due to the highest surface area /unit mass and or lowest diffusional path of 3 mm slices as noted by Islam (1980) and Rahman & Kumar (2007).

Table1. Temperature in the dryer at different heater fan configuration

Configuration	Upper shelf	Lower shelf
1KH-1F	56.7°C	47.0°C
1KH-2F	47.0°C	42.0°C
2KH-1F	70.0°C	50.0°C
2KH-2F	60.0°C	47.0°C

Table 2. Difference of moisture content (db) of potato slices against time for different thickness of sample at Condition: Single Fan (Upper- shelf)

Time (hr)	% Moisture Content (db) For different Thickness					
	3 mm		5 mm		7 mm	
	2KH-1F	1KH-1F	2KH-1F	1KH-1F	2KH-1F	1KH-1F
0	525	525.0	525	525.0	525.0	525.0
1	150	275.0	193.75	387.5	393.75	415.62
2	70.25	125.69	109.37	277.187	278.12	321.25
3	28.2	40.625	75	183.437	193.75	231.25
4	6.25	25.0	37.5	104.687	103.12	153.75
5	3.12	6.25	15.62	79.687	75.0	93.75

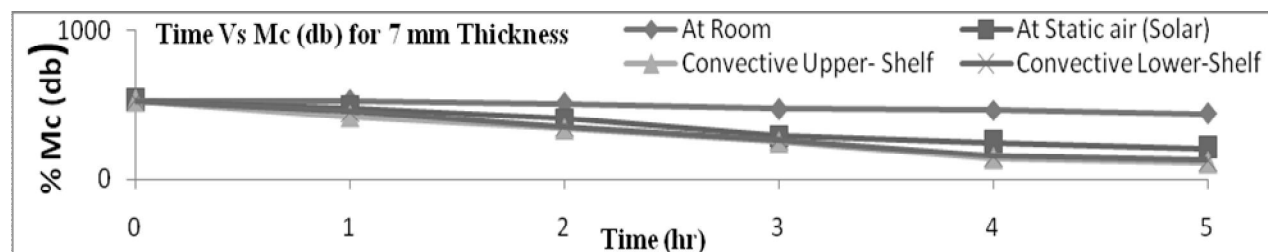


Figure 3. Difference of moisture content (db) of potato slices against time for 7 mm thickness of sample at various conditions

Drying Kinetics

From Table-2 It was concluded that after a certain period of time thicker slices retains higher moisture ratio (MR) than thinner slices. For a particular thickness and drying condition upper shelf requires less time compared to lower shelf due to temperature difference (from equation 1, 3&5) and it was also observed that the drying rate constant are thickness dependent as described by Brooker *et al.* (1974). The experimental drying data were analyzed and plots of moisture ratio versus drying time were made on semi-log scale and regression lines were drawn and the developed equations are given below. The equations of moisture ratio (MR) for 7 mm thick potato slices are as follows:

- MR=1.103e^{-0.40x} (at 70°C)(2KH-1F, upper shelf)....(1)
 - MR=1.030e^{-0.37x} (at 60°C)(2KH-2F, upper shelf)....(2)
 - MR=1.105e^{-0.34x} (at 56.7°C)(1KH- 1F, Upper shelf).(3)
 - MR=1.066e^{-0.29x} (at 47°C)(1KH-2F, upper shelf)....(4)
 - MR=1.022e^{-0.15x} (at 47°C)(At lower shelf for 1KH-1F&2KH-2F).....(5)
 - MR=1.103e^{-0.32x} (at average 40.1°C, natural convection, upper shelf).....(6)
 - MR=1.127e^{-0.30x} (at average 37.7°C, natural convection, lower shelf).....(7)
 - MR=1.055e^{-0.23x} (at average 38.5°C, with 1Fan, upper shelf).....(8)
 - MR=1.060e^{-0.21x} (at average 37.4°C, with 2Fan, upper shelf).....(9)
- X= time in hr.

From equation 1 to 5 it is seen that the highest drying rate constant (0.4 hr⁻¹) was obtained at 70°C (2KH-1F) successively followed by 0.37hr⁻¹ at 60°C (2KH-2F), 0.34hr⁻¹ at 56.7°C (1KH-1F) and 0.29 hr⁻¹ at 47°C (1KH-2F) in the upper shelf, while lowest drying rate constant (0.15 hr⁻¹) was given at 47°C (1KH-1F and 2KH-2F) in the lower shelf. Again from equation 6 to 9 it was seen that natural convection in the upper shelf gave highest drying rate constant (0.32 hr⁻¹) at 40°C which was closely followed by 0.30 hr⁻¹ that found in the lower shelf due to natural convection, while the lowest drying rate constant was 0.21hr⁻¹ at 37.5°C and closely preceded by 0.23hr⁻¹ at 38.5°C that both are found in upper shelf of the drier with 2Fan and 1 Fan configuration respectively. Thus in general it is seen that drying rate constant is more dependent on temperature rather than air flow and higher air flow with constant heater power gave lower temperature condition and higher energy loss in the process of drying.

Diffusion co-efficient and activation energy

From the drying rate constant in equation 1 through 9 (noted in earlier section) Diffusion coefficients were determined (Table.3). It is seen that for 7 mm thickness, 2KH-1F gave the highest diffusion coefficient and was successively followed by 2KH-2F, 1KH-1F, while 1KH-2F configuration gave the lowest diffusion coefficient and are related to lower

temperature attained in the dryer due to respective configuration. Again for solar operation, natural convection gave the highest diffusion coefficient and was followed by single fan configuration while double fan configuration gave the lowest diffusion coefficient and is related to successively lower temperature attained in the dryer due to respective configuration and thus also air flow. In other words

the higher is the temperature (low air flow rate) the higher is the diffusion coefficient. It has been noted that diffusion coefficient is related to inverse absolute temperature by Arrhenius type of equation (Islam, 1980 and Heldman, 1974) and the diffusion coefficient is also related with sample thickness (Rahman& Kumar, 2007).

Table 3. Relationship between Temperature and Diffusion Co-efficient (De) for 7mm thick potato slices at upper-shelf for various conditions

Drying method	condition	1/T _{abs}	D _e (cm ² /sec)	Activation Energy, E _a (Kcal/g-mole)
Mechanical	1KH-2F	0.001972	0.000003999	7.656
	1KH-1F	0.001935	0.00000468	
	2KH-2F	0.001923	0.0000051023	
	2KH-1F	0.001887	0.000005516	
Solar	2F	0.00201	0.000002896	8.252
	1F	0.002006	0.000003172	
	convection	0.0019996	0.000004413	

Thus diffusion coefficient and corresponding inverse absolute temperature data were used to develop exponential type popularly known as Arrhenius equation was developed by regression analysis. The equations are as follows:

$$D_e = 0.008 e^{-3855/T_{abs}^{-1}} \text{ 7mm slice, (Upper shelf, Mechanical type)} \dots\dots\dots (10)$$

$$D_e = 5 \times 10^{-30} e^{-4153/T_{abs}^{-1}} \text{ 7mm slice, (Upper shelf, Solar type)} \dots\dots\dots (11)$$

Where, D_e= Diffusion co-efficient (cm²/s) and T_{abs}=Absolute temperature (°K)

From the developed equations (10& 11) it is seen that activation energy for diffusion of water from potato using mechanical and solar type configurations are respectively 7.656 Kcal/g-mole and 8.252 Kcal/g-mole. These values are within the activation energy values reported by a number of authors such as 7.7 Kcal/g-mole by Islam (1980), 7.98 Kcal/g-mole and 5.6 Kcal/g-mole for two different varieties of potato by Sarker (2009), 8.50 Kcal/g-mole for Cucumber and 7.70 Kcal/g-mole for Cauliflower by Iqbal (2003), 5.2 Kcal/g-mole for Pasta by Xiong *et al.* (1991), 5.25 Kcal/g-mole for Stevia leaves by Syduzzaman and Sharmin (2009) and the difference in activation energy (E_a) might result from differences in product characteristics (such as water activity, moisture content, solid concentration, pH and others), temperature employed for drying and structure of the fresh material undergoing drying as reported by Islam(1980), Iqbal & Islam (2005), Karel (1975), Villota and Hawkes (1992). The differences in activation energy values (7.656 and 8.252) of the current study including mechanical and solar systems

might be attributed to among others, difference of the temperature ranges used.

Thickness dependency of drying rate constant

To investigate the effect of thickness (3, 5 and 7 mm) on drying rate constant, the thickness and the corresponding drying rate constant were plotted in log- log coordinate. And it was found that drying rate constant decreases as the thickness increases thus the drying rate constant is inversely related with the thickness. The several power law equations were established for upper shelf, such as:

$$y = 2.882x^{-1.14} \text{ (1KW-1F)} \dots\dots\dots (12)$$

$$y = 0.790x^{-0.53} \text{ (1KW-2F)} \dots\dots\dots (13)$$

$$y = 2.741x^{-1.3} \text{ (1F)} \dots\dots\dots (14)$$

$$y = 3.063x^{-1.42} \text{ (2F)} \dots\dots\dots (15)$$

From the developed equations (12-13) the “n” values or power law indexes were found less than 2 and these values were lower than that predicted by the theoretical drying equation. The low value of ‘n’ is attributed to presence of significant external resistance to mass transfer (Islam, 1980).

Conclusion

Duct head play a vital role in controlling shelf temperature. Upper shelf is treated as first opening of hot air from duct .There is temperature variation between upper shelf and lower shelf. The temperature in upper shelf can be increased by increasing distance from heating source (heater) and reducing distance from duct head. And the temperature of lower shelf can be increase by reducing distance from duct head.

During drying it was observed that 3 mm thick potato slices become wrinkled. On the other hand, 7 and 5 mm thick potato slices were selected as good dried product. It was also observed that, for a specific moisture ratio, faster drying was achieved for thin samples compared to thicker ones. Activation energy (E_a) for diffusion of water from potato was 7.656 Kcal/g-mole and 8.252 Kcal/g-mole for mechanical and solar system respectively at upper shelf with 7mm thick slices.

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