บทความรับเชิญ

Overview of Dehydration Method on Quality of Fruit and Vegetable

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1. Basic Drying Theory

Drying is one of the oldest methods of preserving food. Primitive societies practiced the drying of meat and fish in the sun long before recorded history. Today the drying of foods is still important as a method of preservation [1]. Drying is traditionally defined as that unit operation which converts a liquid, solid or semi solid feed material into a solid product of significantly lower moisture content. It is a complex process involving simultaneous coupled, transient heat, mass and momentum transport [2]. Food drying also involves simultaneous mass and energy transport phenomena [3].

Dried foods can be stored for long periods without deterioration occurring. The principal reasons for this are that the microorganisms which cause food spoilage and decay are unable to grow and multiply in the absence of sufficient water and many of the enzymes which promote undesired changes in the chemical composition of the food cannot function without water [1].

There are two general processes of drying; adiabatic and non-adiabatic drying processes. The adiabatic dryers involve a drying gas that provides the heat of vaporization and later carries the vapor away from the product. The non-adiabatic dryers involve heat flows into the solids from sources other than the drying gas, e.g. radiation or conduction by contact with a surface [4].

There are several ways to classify the drying methods. Drying methods can be subdivided by the way in which heat is supplied to the moist material and by the mode

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of operation, whether continuous or batch wise. Keey (1975) described four methods of heating which can be seen in drying process, as conductive, convective, radioactive and dielectric [5].

The kinetics of drying phenomena which are complex functions of temperature, moisture content, food composition, and several other factors, have not been sufficiently studied [3].

Quality changes of food materials are common phenomena during drying. Quality parameters are very important and application of drying method should not deteriorate the quality parameters of the food. There are some quality changes during drying of food material. Crapiste (2000) has mentioned about quality changes during drying.

2. Drying Process

In the drying process three types of bound water can be seen in food materials.

1. Water molecules which are bound to ionic groups

2. Water molecules which are hydrogen bonded to hydroxyl and amide groups

3. Unbound free water found in interstitial pores in which capillary forces and soluble constituents could cause lowering of vapor pressure [4].

Drying rate includes different periods, first the moisture is removed by evaporation from the saturated surface, and next the area of saturated surface gradually decreases, followed by water evaporation in the interior parts of the sample. In the drying curve three periods can be identified as warming up, constant rate and falling rate. The exchange point which drying rate changes from constant rate to falling rate of drying curve is termed critical moisture content. The warming up period is of little consequence in most cases because of its short duration. Either the constant rate or falling rate period may constitute the major portion of the drying time.

During the constant rate drying period, the rate of moisture removal from the product is limited only by the rate of evaporation on water surfaces on or within the product [4]. In this constant-rate period, the water is being evaporated from what is effectively a free water surface. The rate of removal of water can then be related to the rate of heat transfer, if there is no change in the temperature of the material and therefore all heat energy transferred to it may result in evaporation of water [1].

Some food materials do not show constant rate drying period. A constant rate drying period was not detected in drying curves of mint [6], chilli [7], apricot [8], orange skin [9], potato, green bean [10], tomato seed [11], carrot, corn, tomato, mushroom, garlic, onion, spinach, green pepper, red pepper, pumpkin, yellow pepper, green pea, leek and celery [12].

3. Basic Dryer Types

Dryers can be classified based on mode of heat input, as convection, conduction, radiation, dielectric heating or combinations of one or more of these modes. Dryers can be further classified on the basis of pressure, temperature of the product during drying, mode of operation, and the method of material handling within the dryer [2].

Different types of dryer are used in the food industry. Present food industry is diversified for producing different kinds of food material. Hence different food drying equipments are developed in different ways.

3.1 Hot Air Drying

Hot air drying, a conventional drying technology, is commonly used for drying grains, fruits, vegetables and nuts. It is based on the flow of dried air through food in the chamber to evaporate moisture in food.

A major disadvantage of hot air drying is low energy efficiency and lengthy drying time during the falling rate drying period. This is mainly caused by rapid reduction of surface moisture and consequent material shrinkage, which often results in reduced heat and moisture transfer. Prolonged exposure to elevate drying temperatures may result in substantial degradation in quality attributes such as color, nutrient, and flavor. Severe shrinkage also reduces bulk density and rehydration capacity.

Torgrul & Dursun (2003) studied the drying behavior of single apricots experimentally with the help of a laboratory tray drying apparatus. Fourteen different drying models were processed to find the most convenient drying model. According to the results of the multiple linear regression analysis, among the 14 models, the logarithmic drying model described best the drying behavior of single apricots (within 99.9%) [8].

Lahsasni et al. (2004) examined the effect of drying air conditions on drying kinetics of the prickly pear fruit in a convective solar drier operating with an auxiliary heating system under air controlled conditions. Eight different thin layer drying models were compared according to their coefficients of determination to estimate solar drying curves. The two-term model was found to satisfactorily describe the solar drying curves of prickly pear fruit with a correlation coefficient (r) of 0.9999 [13].

Akgun & Ibrahim (2005) investigated the thin layer drying kinetics of olive cake at a wide range of drying temperatures (50-110 °C), a constant sample thickness and air velocity of 1.2 - 0.03 m/s at a laboratory scale dryer. Among the various drying models, the logarithmic model was found to give better predictions than the others [14].

3.2 Microwave Drying

Microwaves are a form of electromagnetic energy. Polar molecules and free ions in receptive materials respond to these fields by creating a molecular friction which results in heat throughout the mass of the material.

Microwave heating offers numerous advantages in productivity over conventional heating methods. These advantages are as follows.

- High speed
- Energy penetration

Microwave energy penetrates to generate heat internally as well as at the surface of the treated material. Other methods apply heat only to the surface and temperature must be limited in order to avoid burning. Conventional processing time is slow due to thermal conductivity. Microwave energy overcomes those time and temperature limitations and produces a very high quality product even when the materials being processed are fairly thick.

- Selective energy absorption

Some material absorbs microwaves rapidly, others do not. This characteristic is an advantage in the microwave process. Pharmaceuticals, for example, can be pasteurized within their packages without burning the packaging material.

- Instantaneous electronic control

Most conventional heating system, i.e. hot air drying, requires appreciable amount of time to affect temperature changes. Microwave power levels can be adjusted electronically in a fraction of a second.

- Effectiveness

Microwave processing requires fewer BTU’s for the same or better results than conventional equipment.

However, an inherent problem associated with microwave drying is the nonuniformity in heating caused by an uneven spatial distribution of electromagnetic field inside the drying cavity. During drying processes, nonuniform heating may cause partial scorching in high sugar products.

3.3 Infrared Drying

Radiation heat transfer is the transfer of heat energy by electromagnetic radiation. Radiation operates independently of the medium through which it occurs and depends upon the relative temperature, geometric arrangement and surface structure of the materials that are emitting or absorbing heat [1].

Infrared heaters run on either electricity or gas. Infrared is electromagnetic radiation with wavelength in the 1- 20 micron range and are divided into three classes according to the wavelength emitted: long wave, in which the radiation is in the 4 - 10 micron wavelength range; medium wave, in which the wave length is in the 2 - 4 micron range; and short wave, in which the wavelength is less than two microns. In infrared heating, the rate of heat transfer depends on the difference between the 4^{th} power of the temperatures of the radiation and the absorbing surfaces. This means that very high rates of heat transfer can be achieved [15].

Infrared emitters can be divided into a number of types:

1. Halogen
2. Short wave
3. Medium wave
4. Fast response medium wave
5. Long wave [15].

Solar energy consists of approximately 48% of infrared energy and is an important drying method in some countries. It is not however widely used as a single source of energy for drying solid pieces of food because of the rapid surface heating of food seals in moisture and flavor or aroma compounds [16].

The advantages of infrared drying are as follows.

- High efficiency conversion of electrical energy into heat for electrical infrared radiation
- High heat transfer coefficients
- Quick start up and shut down
- Short process time
- Low cost of energy

The limitations of infrared dryer are as follows.

- Difficult to work with temperature sensitive substrates
- Scaling up of the heater is not always straightforward

Togrul (2005) examined the infrared drying of fresh apple slices, and the experimental drying data were applied to Newton, Page, Modified Page, Wang and Singh, Henderson and Pabis, Logarithmic, Diffusion approach, Simplified Fick's diffusion SFFD equation, Modified Page equation-II and Midilli equation. Midilli equation was the best for characterizing drying behavior of apples for the whole range of temperatures [17].

Infrared drying characteristic of carrots was investigated by Togrul (2006) in the temperature range of 50-80 °C in an infrared dryer. Five empirical drying mode ls Newton, Modified Page, Logarithmic, Diffusion approach and Midilli were used to evaluate the drying kinetics. The Midili model reported to give the best result [18].

3.4 Vacuum Drying

Vacuum drying is the removal of liquid material from a solution or mixture under reduced air pressure, which results in drying at a lower temperature than is required at full pressure. Vacuum drying can be applied in a variety of food to remove water through evaporation or sublimation. Vacuum alters vapor pressure to enhance evaporation rates as well as increases the drawing out of liquids in pastes by capillary pressure. The process is essentially a thermal process whereby heat is transferred to the material by conduction through the dryer's heated surface. Often agitation and/or tumbling can be employed to enhance the drying process.

Mongpraneet et al. (2002) studied on accelerated drying of Welsh onions by far infrared radiation under vacuum conditions and stated that only moisture transfer in the vacuum operation was vaporized from the products over long time, but the penetration of internal heating into the products caused a rapid increase in water vapor pressure inside the materials. Thus, far infrared radiation can be combined effectively with vacuum operation to ensure rapid removal of evaporated moisture [19].

Pinedo & Murr (2006) studied the drying kinetics of pumpkins by using a vacuum dryer. The diffusional model with and without considering the shrinkage with three terms of the Fourier series proved to be excellent to fit the drying curves of pumpkins [20].

3.5 Microwave-Vacuum Drying

Microwave-vacuum drying offers an alternative way to improve the quality of dehydrated products. The low temperature and fast mass transfer conferred by vacuum combined with the rapid energy transferred by microwave heating, generate a rapid and low-temperature drying. Microwave-vacuum-dried foods showed better retention of key constituents and sensory properties than air-dried counterparts [21]. Yongsawatdigul and Gunasekaran (1996a) also remarked that the microwave-vacuum drying technique has been successfully applied to numerous food materials, including fruits, vegetables and grains [22].

It seems that microwave-vacuum drying with pressures above the triple point of water has more commercial potential. Obviously, microwave energy has a benefit in overcoming the disadvantage of very high heat transfer and conduction resistance and also leads to higher drying rates. These high drying rates correspond to the retention of water insoluble aromas [23] and less shrinkage. The use of vacuum pressures is favorable for high quality food substances since the reduced pressure limits the product temperatures to lower values when a certain amount of free water is present. This enables the retention of temperature sensitive substances such as vitamins and colors. Commercial applications of microwave-vacuum dehydration are the concentration or even powder production of fruit juices and drying of grains in short periods without germination [24].

Microwave-vacuum dehydration characteristics of button mushroom (*Agaricus bisporus*) was evaluated by Giri & Prasad (2007) in a commercially available microwave oven (0-600 W) modified to a drying system by incorporating a vacuum chamber in the cavity. The exponential as well as empirical Page's models adequately described the microwave-vacuum drying characteristics [25].

4. Quality Changers in Foods during Drying

The quality of dried foods depends not only on the drying process but the quality of raw materials, pretreatment process (i.e., blanching, chemical treatment, freezing) and storage condition of the final product. The major effects of dehydration that cause quality degradation in fruits and vegetables are summarized in Table 1.

Table 1 Quality changes in foods during drying

Type	Factor	Quality Effect
Physical and structural	Shrinkage Cell structure damage Volatile retention	Volume, texture, rehydration ability Texture, rehydration ability, solute loss Aroma loss
Chemical and organoleptic	Browning reactions Lipid oxidation Pigment degradation Enzyme inactivation	Darkening, off-flavor development Rancidity, off-flavor development Color loss Flavor and pungency loss
Nutritional	Microbial death Protein denaturation Vitamin degradation	Microbial survival Loss of biological value Loss of nutritive value

Source: Crapiste (2000) [3]

4.1 Rehydration Ratio

Rehydration is one way to analyze quality of dried products. The high value of rehydration ratio means the dried product has a good quality because the pores allow water to reenter into cells. The rehydration ratio is estimated from the ratio of weight of rehydrated sample to weight of dried sample.

Sharma et al. (2005) applied infrared radiation drying on onion slices and found that the range of the rehydration ratio of dehydrated onion slices was 4.5 to 5.3 mm., under infrared power levels of 300, 400 and 500 Watts (W), which are about two folds higher than the observed value of about 2.4 for a convective dried commercial onion sliced sample [26].

Prakash et al. (2004) investigated on performance evaluation of blanched carrots dried by microwave vacuum drying and found that the rehydration properties were improved by drying at high temperature or power levels. This is because during drying under these conditions, the rate of removal of moisture is very fast and causes less shrinkage, thus facilitating rehydration [27].

4.2 Color

Physical characteristics of food include particle size, metting point and specific gravity but color is not one of them. Rather, color is a psychological products that affects the enjoyment of eating. One method to measure color is using colorimeter which shows in values of L, a and b. L value shows the degree of brightness, a value shows the degree of redness (+a) or greenness (-a), b value shows the degree of yellowness (+b) or blueness (-b). Temperature and relative humidity during drying are the causes of color degradation in dehydrated products [28].

Yongsawatdigul and Gunasekaran (1996b) investigated the effect of microwave- vacuum drying on color of dried cranberries. The result showed that microwave-vacuum dried cranberries were redder than those dried by the conventional hot-air method [29].

Mongpraneet (2002) studied on accelerated drying of Welsh onions by far infrared radiation under vacuum conditions and found that rehydration of onions by soaking in distilled water demonstrated that a change in the a parameter was more obvious than that in the b parameter. For the effect on the L parameter, the dehydrated product was moved by the radiation intensity closer to whiteness, while the rehydrated product showed a fluctuating effect with intensity level and was closer to the blankness of the initial product [19].

4.3 Volatile Component

Decareau (1985) stated that when considered the product quality factors, with the exception of methanol, microwave-vacuum drying has been shown to have less effect on volatile components of dehydrated juice than either spray or freeze drying as shown in Table 2.

Table 2 Retention of volatile components as a function of drying methods

Component	Retention (%)		
	Spray drying	Freeze drying	Microwave-vacuum drying
Reducing volatiles	11.0	33.1	82.5
Ethyl acetate	2.0	23.5	31.1
Methanol	150.0	-	42.5
Ethanol	6.7	-	57.0
Ethyl butyrate	7.2	42.9	59.2

Source: Decareau (1985) [24]

The effect of the drying method on the relative content of major flavor volatiles of oregano (*Lippia Berlandieri* Schauer) was evaluated by Yousif et al. (2000). The result showed that the level of major volatile compounds in microwave-vacuum-dried oregano was found to be comparable to the fresh sample.

Viscardi et al. (2003) studies the change in chemical composition of dried basil leaves using microwave drying, air drying and freeze drying. The results showed that percentage retentions of the volatile compounds of microwave-dried samples were higher than the samples dried by traditional methods, with the exception of freeze-dried basil [30].

5. Case Study on Vacuum Infrared and Microwave Vacuum Drying on Vegetable Arch

Due to the study of Unkaroonchaikul and Noomhorm (2007), effect of infrared radiation intensity with and without vacuum on quality of dried red onion slices was investigated as shown in Table 3. It showed that the vacuum infrared drying at 500 Watts presented the best quality of dried red onion slices, with the shortest drying time, highest of rehydration ratio and lowest of the a/b value. Therefore, this condition was considered as the most suitable drying condition for drying red onion slices [31].

Table 3 Effect of different drying methods on quality of dried red onion slices

Condition	Drying time (hr)	Rehydration ratio	L value	a/b value
Fresh red onion	-	-	47.00±0.03[d*]	2.38±0.04[f]
Hot air, 60 °C	9.67	4.66±0.01[e]	50.95±0.02[g]	0.41±0.00[bc]
Infrared, 300 W	5.83	4.16±0.03[a]	42.26±0.02[b]	0.56±0.00[e]
Infrared, 400 W	4.83	4.46±0.04[b]	45.42±0.02[c]	0.50±0.00[d]
Infrared, 500 W	3.33	4.64±0.03[de]	41.94±0.03[a]	0.56±0.00[e]
Vacuum-infrared, 300 W	1.83	4.55±0.03[e]	49.58±0.03[f]	0.43±0.00[c]
Vacuum-infrared, 400 W	1.33	4.61±0.01[d]	52.52±0.01[h]	0.40±0.00[b]
Vacuum-infrared, 500 W	1.17	4.74±0.02[f]	48.47±0.01[e]	0.36±0.00[a]

Note: *Means for each characteristic followed by the same letter are not significantly different at $P>0.05$ by LSD test

From the study of Jirakitkul and Noomhorm (2007), the effect of drying conditions on drying characteristic, rehydration ratio (RR), color of mulberry leaves was investigated as shown in Table 4. The summarized data revealed that microwave - vacuum drying at the highest power level, 452 + 2.12W, yielded the shortest drying time and the highest rehydration ratio which indicated the least shrinkage in mulberry leaves. The color parameters of microwave-vacuum dried mulberry leaves at 452 + 2.12W were not significantly different from vacuum dried mulberry leaves at 70°C which showed the greatest color parameters. The preference scores of tea color also showed the best value in microwave-vacuum dried mulberry leaves at 452 + 2.12W. All reasons above indicated that microwave-vacuum drying at 452 + 2.12W possesses the highest potential for drying mulberry leaves required for making mulberry tea [32].

Table 4 The effect of drying conditions on dried mulberry leaves

Drying conditions	Drying time, min	RR	Color parameters			Tea color preference scores
			L	a	b	
Hot air drying temperature, °C						
70	Final MC>5%wb	-	-	-	-	-
80	400	3.914	19.61[a]*	-2.34	6.33	5.9
90	130	3.796	18.16	-0.91	8.48	5.8
Vacuum drying temperature, °C						
70	150	4.152	21.46[b]	-2.95[e]	7.86	6.4
80	120	4.104	19.73[a]	-2.76[f]	8.83[g]	6.3
90	90	4.018	19.27	-1.43	9.38[h]	5.9
Microwave vacuum drying power, W						
186.33 ± 2.33	7.5	4.162	21.92[c]	-2.23[d]	7.17	6.7
335.59 ± 3.22	6	4.186	22.23	-2.82[ef]	8.76[g]	6.8
452.64 ± 2.12	5.5	4.227	21.71[bc]	-2.92[e]	9.28[h]	6.8

Note: *Means for each characteristic followed by the same letter are not significantly different at $P>0.05$ by LSD test

Conclusion

Drying methods are classified into adiabatic and non-adiabatic drying processes. The adiabatic process involves the heat of vaporization and transfer of heat from the product by convection and conduction such as hot air drying and solar drying. The non-adiabatic process uses the radiation by electromagnetic waves in which heat flows into the solid from the sources other than heating the medium like gas. The characteristic of drying for radiation heat depends on the relative temperature, shape or geometric arrangement and surface structure of materials. The efficiency of drying, drying time and quality changes of food materials are different from conventional drying such as hot air drying. For radiation, the applications on heating and drying are well accepted by the processor but in terms of food sterilization it needs to be further developed due to nonuniform distribution of heat.

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