Going beyond conventional osmotic dehydration for quality advantage and energy savings

Yetenayet Bekele and Hosahalli Ramaswamy*
Department of Food Science and Agricultural Chemistry, McGill University, Macdonald Campus, 2111 Lakeshore Road, Ste Anne de Bellevue, Quebec, H9X 3V9, Canada
*Corresponding author: Tel 514-398-7919; E-mail: hosahalli.ramaswamy@mcgill.ca

(Received in revised form: November 16, 2010)

ABSTRACT

Osmotic drying is a partial dehydration process, often considered more as a treatment, to give the product a quality improvement over the conventional drying process. The osmotic treatment involves soaking of a food in hypertonic solution of sugar and/or salt for specific times under controlled temperature condition. The process involves two counter-current mass transfers, a loss of water from the food to the solution and the simultaneous migration of solids from solution to the food. Such mass transfer phenomena are governed by pretreatment, osmotic solution, product and osmotic environment related factors. The method has two major advantages when combined or compared with other drying methods. The quality of osmotically dehydrated products is better and shrinkage is considerably lower as compared to products from conventional drying processes. Secondly, the technique helps to conserve the overall energy relative to other drying procedures. The first aspect has been widely studied while the energy aspects are addressed rather scarcely. The major objective of this paper is to discuss the advantage of osmotic dehydration in terms of energy reduction and its potential contribution to maximize profit by reducing the associated costs. The osmotic dehydration step can be done before, during or after the conventional drying process to enhance the mass transfer rate or to shorten the duration of drying time. After the osmotic treatment, the moisture content of fruits and vegetable are usually reduced by 30-50% (wet basis). The amount of residual moisture in the product determines the duration and the energy required to finish dry the product to achieve the desired product stability. This reduction in moisture has a significant impact in conservation of energy when the technique complements other conventional drying methods like convective, freeze, microwave and vacuum drying. Moisture removal by phase change (evaporation of water) is an energy intensive process due to high latent heat of vaporization of water. During osmotic dehydration, there is no phase transition and the process can be done with minimum supply of energy, which is the principal reason for the energy savings. Novel approaches in food drying are constantly being explored to minimize the energy demand and maximize profit.

Keywords: Osmotic, dehydration, drying energy, efficiency

INTRODUCTION

Osmotic dehydration (OD) is a dehydration process of foods that involves soaking a food in hypertonic sugar and/or salt solution to reduce the moisture content of foods before actual drying process. OD is performed to reduce the moisture content of food products in minimal processing under ambient or modified environment.
During the process two simultaneous counter-current flows may occur; water-flow out of the food into the solution, the simultaneous transfer of water soluble solutes from the solution into the food, and migration of natural solutes (sugars, organic acids, vitamins, reducing sugars, some flavor compounds, volatiles, minerals, etc.) from the food into the solution (Le Maguer and Biswall, 1988). The process can be represented as shown in Fig 1. Since the hypertonic solution has higher osmotic pressure with reduced water activity, it serves as a driving force for water withdrawal from the cells solution to the osmo-active solution. The removal of water during osmotic process is mainly by diffusion and capillary flow, whereas solute uptake or leaching is only by diffusion (Rahman, 2007). All these mass exchanges between the osmotic solution and foodstuff may have an effect on the overall yield and quality of the dehydrated product.

**Osmotic dehydration**

![Figure 1. Osmotic dehydration principles and relative mass flow of water and solutes.](image)

In perfectly semi-permeable membrane, the solution is unable to transfer through the membrane into cells, but it is hardly to obtain such type of membrane in food materials due to its complex internal structure and possible damages during processing (Shi, 2008). Hence, such conditions are important in osmotic dehydration processes to allow counter flow of solutes and water. In plants due to semi-permeable nature of plant tissue and low molecular size of water molecules the flux of water coming out of the food is much larger than solute gain from osmo-active substance. This result in a decrease of water content of the product with time till equilibrium condition is established. Therefore, the weight of the foodstuff will decrease, as well the water activity. According to some works, it is reported that up to 50% reduction in the fresh weight of fruits or vegetables can be achieved by osmotic dehydration (Rastogi and Raghavararo, 1997).

**FACTORS AFFECTING MASS TRANSFER KINETICS**

Osmotic dehydration as a mass transfer process it is affected by different factors. The kinetics of mass transfer is usually described using terms such as water loss (WR), solids or solutes gain (SG) and weight reduction (WR) (Shi, 2008). The overall mass transfer kinetics during osmotic dehydration is affected by several factors. By manipulating processing factors affecting mass transfer, and nature of the product subjected to dehydration it is possible to reach different levels of dehydration or impregnation of the material under treatment. In the following subsections the effects of those various variables will be briefly discussed.

**Pre-treatment factors**

Pre-treatment conditions before osmotic dehydration process affect product inherent integrity which has an effect on mass transfer process. Osmotic dehydration rate is largely affected by cell membrane permeability (Toupin
Good membrane permeability ultimately will lead to more rapid osmotic dehydration. However, the cellular membrane of plant cells exerts high resistance to transfer of water and solutes and slows down the overall osmotic drying rate (Erle and Shubert, 2001). Therefore, the partial damage of cell membranes using different pre-treatment methods can be advantageous for acceleration of mass transfer process. Blanching (Islam and Flink, 1982; Allali et al., 2009), peeling, coating (Lewicki et al., 1984; Camirand et al., 1992; Ishikawa and Nara, 1993; Wong et al., 1994; Lazarides, 2001; Matuska et al., 2006), freeze/thawing (Ponting, 1973; Hilderbrand, 1992; Lazarides and Mavroudis, 1995; Sormani et al., 1999; Maestrelli et al., 2001), high pressure from 100-800 MPa (Dornenburg and Knorr, 1993, 1998; Rastogi et al., 1994, 2000; Lazarides, 2001; Tedjo et al., 2002), and high intensity electric field pulses (Rastogi et al., 1999; Taiwo et al., 2003) are some of the pre-treatment operations which are used before osmotic dehydration process to enhance mass transfer.

**Product related factors**

On the product side, species, variety, and maturity level all have a significant effect on natural tissue structure, in cell membrane structure, propectin to soluble pectin ratio, amount of insoluble solids, intercellular spaces, tissue compactness, entrapped air and etc (Lazarides, 2001). Furthermore chemical composition (protein, carbohydrate, fat, and salt), physical structure (porosity, arrangement of the cells, fiber orientation, and skin), may affect the kinetics of osmosis in food (Rahman, 2007). Particularly porosity of the raw material has a significant effect on shrinkage phenomena and mass transfer rates (Mavroudis et al., 1998a) as well as rehydration ratio. The shape/geometry and size (Contreras and Smyrl, 1981) of product affect the surface area to volume ratio of the product with the solution. Since solute impregnation is a surface-controlled phenomenon, high specific surface values favour solute uptake (Lerici et al., 1985; Torreggiani, 1993).

**Osmotic solution related factors**

Osmotic process is also affected by the physicochemical properties of the solutes employed, because differences in efficiency of dehydration arises mainly from differences in molecular weight, ionic state, and solubility of solute in water (Rahman, 2007). The selection of the solute must consider the following three main factors: (i) solute impact on sensory characteristics of the product, (ii) the relative cost of solute in relation to the final value of the product, and (3) the molecular weight of the solute. Some of the solutes often used in osmotic dehydration processes are sodium chloride, saccharose, glucose, and corn syrup.

Penetration studies showed that the rate of solute penetration is directly related to the solution concentration and inversely related to the size of the sugar molecule (Panagiotou et al., 1999; Giraldo et al., 2003). For instance by using higher molecular weight sugars (i.e., lower dextrose equivalent corn syrup solids) it was possible to zero net solute gain (Lazarides and Mavroudis, 1995) and allows only migration of moisture. In other works confirmed that glucose resulted in higher amounts of water loss and solid gain than sucrose (Bolin et al., 1983; Lerici et al., 1985; Garrote and Bertone, 1989; Panagiotou et al., 1999; Taiwo et al., 2003). Lenart and Flink, (1984) found that mixed sucrose/salt solutions gave a greater decrease in product water activity than pure sucrose solutions, although water transport rates were similar. The pH of
the solution can also affect the osmotic process. Acidification increases the rate of water removal by changes in tissue properties and consequential changes in the texture of fruits and vegetables (Moy et al., 1978).

**Osmotic environment related factors**

Environmental conditions during osmotic dehydration process are main factors that play important role in rate of water withdrawal and solutes migration processes. Among several environmental factors, temperature, duration of treatment time and other environmental factors are the most important parameters influences the kinetics of water loss and solute gain. The positive effect of temperature and time on the removal of water from the food during osmotic treatment has been shown by several works. Water loss increases with increase in temperature, whereas solid gain is less affected by temperature (Beristain, 1990; Li and Ramaswamy, 2006a). During osmotic dehydration of potatoes, increasing process temperature up to 45°C resulted in increased WL and SG rates, in favor of higher WL/SG ratios (Lazarides, 2001). Obviously with an increase in osmotic treatment time, mass transfer process increased till both water and solute concentrations attain their equilibrium conditions. Osmotic dehydration for a short contact time minimized color losses during convective air-drying of blueberries (Nsonzi and Ramaswamy, 1998). However a longer contact time of the samples with the sugar solution gives a higher solids gain and a higher moisture loss (Nieuwenhuijzen et al., 2001). Osmotic dehydration can be enhanced by agitation or circulation of the syrup around the sample (Lenart and Flink, 1984; Mavroudis et al., 1998b). Turbulent solution flow due to agitation may result in higher WL/SG ratios (Lazarides, 2001).

Vacuum osmotic dehydration results in a change of behaviour of mass transfer in fruit sugar or salt solution systems (Shi and Maupoey, 1994; Shi et al., 1995). The reduction in pressure causes the expansion and escape of gas enclosed in the pores, and pores can be occupied by osmotic solution, thus increasing mass transfer rate (Fito et al., 1994; Chiralt et al., 1999; Rahman, 2007). Effect of vacuum on enhanced rate of OD of different foods is indicated in different works (Fito, 1994; Rastogi and Raghavarao, 1994; Shi and Fito, 1994; Shi et al., 1995; Moreno et al., 2000; Taiwo, et al., 2003). Ultrasound also used as a means to enhance mass transfer process during osmotic dehydration of fruits (Simal et al., 1998; Rodrigues et al., 2009). Rodrigues et al. (2009) elucidate the effect of ultrasonic waves with analogy of the sponge effect. According to him the wave can cause a rapid series of alternate compressions and expansions, in a similar way to a sponge when it is squeezed and released repeatedly. Continuous compression and relaxation of the wave may be the main cause for the creation of microscopic channels in porous materials such as fruits (Fuente-Blanco et al., 2006). Furthermore, cavitation, a phenomenon produced by sonication, consists of the formation of bubbles in the liquid, which can explosively collapse and generate localized pressure and this effect accelerates and completes degassing, resulting in increased diffusion in the osmotic process (Taiwo et al., 2003). Generally temperature, duration of treatment time, osmotic solution concentration, and vacuum level are the most important variables in the osmotic process (Corrêa et al., 2010).
BENEFITS OF OSMOTIC DEHYDRATION

There are two major advantages of osmotic dehydration process in the food industry (i) quality aspect (improvement in terms of color, flavor, texture, product stability and retention of nutrients during storage and (ii) energy efficiency. The importance of osmotic dehydration in terms of quality aspects extensively discussed in several articles. In the following sub-section more focus is given to discuss from energy efficiency point of view.

Quality issues
Osmotic pre-concentration is an effective way to reduce water content with minimal damage on fresh product quality. This is largely due to the use of a mild product treatment at relatively low process temperatures (30-50°C); such temperatures do not affect the semi-permeable characteristic of cell membranes, which is an essential requirement for maintaining the osmotic phenomenon (Lazarids, 2001). Because of constant product immersion in the osmotic medium, the plant or animal tissue is not exposed to oxygen; therefore, there is no need to use antioxidants (i.e., sulfur dioxide in case of fruits) for protection against oxidative and enzymatic discoloration (Dixon et al., 1976). Dehydration of foodstuffs by immersion in osmotic solutions before convective air-drying improves the quality of the final product since it prevents oxidative browning and/or loss of volatile flavouring constituents, reduces the fruit acidity (Ponting, 1973). On the other hand, partial dehydration and solute uptake have advantages in preventing structural collapse during subsequent drying processes (Lazarides and Mavroudis, 1995; Simal et al., 1997).

Osmotic treatments prior to freezing are used to produce several kinds of fruits that can be stored for long periods of time with good retention of texture, colour and flavour after thawing (Sormani et al., 1999; Maestrelli et al., 2001) and prevent loss of extensive drip loss on freeze/thawing (Lazarides and Mavroudis, 1995). Water content reduction and sugar gain during osmotic dehydration have been observed to have some cryoprotectant effects on colour and texture in several fruits (Chiralt et al., 2001). In addition to this it has been proven to be a good method to obtain minimally processed fruits, due to the great sensory similarity between the dehydrated and natural product. The use of osmotically dried fruits to make high quality chips is one application area to get good quality vacuum fried product. Because of the high sugar content of the product after osmotic dehydration, vacuum frying is a method to produce high-quality deep-fat fried fruit chips both in sensorial and textural quality parameters. The best mango chip in vacuum frying was produced with an osmotic solution concentration of 65% (w/v) and temperature of 40°C, which resulted in the highest water loss to sugar gain and provided a good texture characteristic (Nunes et al., 2009).

Energy saving
Drying is one of the most energy intensive unit operations in food and non-food products processing industries. This is mainly because of high latent heat of vaporization of water to be removed from a product. According to Kudra (2004), for batch drying, the energy efficiency is therefore given as an average value over a drying time and for continuous drying the energy efficiency is averaged over the range of moisture content, or the dryer length, or volume, depending on dryer configuration. In all cases the drying efficiency and energy demand is
Yetenayet Bekele & Hosahalli Ramaswamy

associated with drying time, which is highly related with volume of moisture in a material to be removed or the rate at which drying accomplished.

OD has diverse application in fruit and vegetable processing industries. However this dehydration step generally does not produce product of low moisture content having long shelf life and stability. To get relatively stable product the technique should complement with other drying methods like; convective, freeze, microwave or vacuum drying steps. Therefore harmonization of osmotic dehydration with these energy demanding drying technologies has a merit in terms of maximizing energy use efficiency and reduction of production cost. In OD a significant amount of water is removed in liquid form (not in vapour form) which demands little or no external energy supply (Lazaridis, 2001). By reducing the moisture content of a product to certain, extent either using mechanical or OD method, ultimately reduce the energy demand required to remove the moisture. In this section the benefit of OD in terms of energy efficiency point of view will be discussed for the common hybrid (osmo-) drying methods.

**Osmo-convective drying**
The majority of artificial drying operations are based on hot air drying, where air is heated by the combustion of fossil fuels or using electric heater prior to being forced through the product. According to Mujumdar and Beke, (2003), typical convective dryers account for about 85% of all industrial dryers. Heating of air before drying is the most energy-intensive processes in food processing industries. Thus, novel thinking in the technology of drying methods to minimize the energy demand is very important. The food industry could save much money by avoiding costly energy demand and waste. Beedie (1995) stated that, improving energy efficiency by only 1% could result in as much as 10% increase in profits. According to this author, energy can be saved by (a) reducing drying time, (b) avoiding heat losses, (heat loss with the exhaust air, heat loss with the product, radiation heat loss from the dryer, heat loss due to leakage of air from the dryer, and heat loss due to over drying of products, and (c) heat recovery from exhaust gas and dried product. By reducing the moisture content before final drying step, the drying time and heating load can be significantly reduced. Therefore, OD as an upstream pre-treatment step of convective air drying process enables to reduce the energy demand for heating and evaporation of the product moisture.

Removal of water in its liquid state rather than the vapour state allows the latent heat of vaporization to be captured, and only a small amount of sensible heat is lost with the condensate (Rahman and Perera, 2007). Mujumdar (2007) indicated that, almost 99% of the applications in drying involve removal of water which has higher energy consumption because of high latent heat of vaporization of water, which is 2676 kJ/kg at 100°C. The more water needs to be removed during convective drying process, the more latent heat of vaporization of energy is demanded. But by reducing the volume of moisture removed from the product on upper stream of actual drying process through OD, the demand for energy can be reduced. For instance fresh fruits and vegetables contain 75 to 95% water and one way to reduce this high water content, before actual drying process is the use OD. As stated before, OD can remove up to 50% (Rastogi and Raghavararo, 1997) of the water in the original fruits or vegetables. Hence, as
compared to the original moisture content the energy demand to remove the remaining moisture to the desired level of drying is by far less than what has been required for osmotically untreated product.

Osmotically dehydrated apples shows no constant rate convective drying period, because the water content is below its critical value, and it reduces the total energy consumption by 24 to 75%, depending on the process conditions and the method to reconstitute the hypertonic solution (Kudra, 2009). According to the same author convective drying of apples consumes ~5000 kJ/kg evaporated water, and nearly 40% of the water evaporated during the constant rate period, even though there is 10 to 25% reduction in drying time due to surface layer of concentrated syrup. The energy use efficiency of osmo-convective drying as compared to conventional convective drying method of apple slices indicated in (Strumillo and Adamiec, 1996). The result confirmed that the significant benefit of osmotic treatment before convective drying method to minimize the energy demand required in the overall drying process. Furthermore Grabowski et al. (2002) noted that drying of fresh cranberries starts at a high moisture content of about 87% (wet basis) but the finished drying of osmotically dehydrated cranberries begin at a moisture content of about 50% of wet bases. This means energy saving of about 2150 kJ of energy per kilogram fresh berries can be obtained when convective vibrating fluid bed or pulsed fluid bed drying methods followed OD process (Kudra, 2009).

Osmo-freeze drying

The freeze drying process consists mainly of two stages: (1) the product is frozen, and (2) the product is dried by direct sublimation of ice under reduced pressure. Freeze-dried products that have been adequately packaged can be stored for longer time, maintaining most of the desirable physical, chemical, biological, and sensorial properties of the fresh product. In freeze drying, frozen material is subjected to a pressure below the triple point and heated to cause ice sublimation to vapor. The method is usually used for high-quality dried products, which contain heat-sensitive components. Furthermore the virtual absence of air and low temperature prevents deterioration due to oxidation or chemical modification of the product and gives very porous products, with high rehydration rates. However, freeze drying is a slow and expensive (high capital and operating costs) process and mainly used for high-value products (Cohen and Yang, 1995) and due these reasons its application on wide range of fruits and vegetables has been limited (Hammami and Rene, 1997). In addition to this the long processing time requires additional energy to run the refrigeration and compressor units, which makes the process very expensive for commercial use. The extended processing time during freezing and condensation processes is mainly due to high water content nature of fruit and vegetable crops. By reducing the moisture level to some extent there is a possibility to shorten the required processing time and associated energy demands.

Robbers et al. (1997) carried out an experiment to evaluate the effect of OD of kiwi fruit during freezing process. They conducted the experiment first by immersing fresh kiwi fruits in 68% (w/w) aqueous sucrose solution to dehydrate for 3 h, then subjecting to an air-blast freezer with an air velocity of 3 m/s and temperature of -3°C. The experiment showed that freezing began
at a lower temperature in the dehydrated product and the temperature of the dehydrated samples was reduced to -18°C in 19–20 min, which was about 20–30% faster compared to untreated kiwi, which required the freezing time of 23–24 min. Generally speaking, lower water content of dehydrated food always induces a lower freezing point and a shorter freezing time as there is less water to freeze and consequently less heat to remove (Spiazzi, 1998). This confirms that a reduction in moisture content of food can reduce refrigeration load during freezing which has a significant impact on energy reduction.

The energy distribution and consumption of individual operations of freeze-drying was established by Liu et al. (2008), they investigated the effects of various operation conditions on the energy losses in the three stages of freeze-drying operations. According to their result the energy consumption in the primary drying reaches 35.7%, in vapor condensing reaches 31.8% and 23.3% in the vacuum pumping of the total energy input. According to them about 67% of the total energy input is used in primary drying phase and condensation of the vapour. Therefore by reducing the volume of moisture frozen through OD the volume of water to be evaporated during primary drying and condensation operations can be minimized. Reduction in moisture content through OD contributes in reducing freezing, primary drying and condensation loads, and consequently a reduced energy demand for overall freeze drying operation.

**Osmo-microwave drying**

The major draw-back of hot-air drying method, from an energy efficiency point of view, is the longer drying period, higher drying temperature and therefore high energy consumption, which may be as high as 6000 kJ/kg of water evaporated (Mujumdar and Menon, 1995; Alibas, 2007). To cope up these limitations microwave assisted drying is used as an alternative solution. The removal of moisture by microwave drying has the following benefits when compared with convective drying: fast and volumetric heating, higher drying rate, shorter drying time, more homogenous energy distribution throughout the material and higher quality of the product and reduced energy consumption (Sanga et al., 2000; Zhang et al., 2006). However, the microwave-drying process can have very high capital costs. In addition to this the technology requires relatively expensive electricity energy, and due to this limitations it is only used in the final stages of drying (finish drying), where it can be used more efficiently than hot air (Gunasekaran, 1999).

Microwave radiation generates rapid volumetric heating of a wet material by altering the electromagnetic field to interact primarily with polar water molecules and ions in food materials (Varith et al., 2007). In comparison of convective air drying microwave drying offers significant energy savings, with a potential reduction in drying time up to 50% in addition to the inhibition of surface temperature of treated material (McLoughlin et al., 2003). Because of its special heating behaviour and high heating efficiency, microwave fields have been applied successfully to assist many drying processes. Several studies have shown that using pre-treatments prior to microwave drying could decrease drying time and thus drying costs (Drouzas and Schubert, 1996). To improve microwave-assisted drying, there are many combinations to be considered for study. Among these combinations, researchers have shown that osmotic drying prior to microwave-
assisted drying leads to lower energy consumption and better qualities of dried product (Venkatachalapathy and Raghavan, 1999; Prothon et al., 2001; Beaudry et al., 2003). A combination of OD with microwave-convective drying appears as a promising possibility in production of dried fruits and vegetables with energy reduction benefits. These days partial dehydration by osmosis has been widely employed prior to microwave drying, as a means of reducing processing time, and thus limiting energy consumption and improving sensory characteristics (Erle and Schubert, 2001; Piotrowski et al., 2004).

According to work of Al-Harashan et al. (2008), on tomato pomace (33% seed, 27% peel and 40% pulp) osmotic pre-treatment before microwave drying experiment, found that the dielectric properties of the product were modified with increase in dielectric loss factor and decrease in dielectric constant which eventually enhanced the drying rate. Dielectric constant reflects the capacity and ability of the material to store electric energy when it is in an electromagnetic field. Dielectric loss factor reflects the resistance and ability of the material to dissipate electric energy in the form of heat during electromagnetic heating. OD performed on mushroom with salt solutions of 10 and 15% reduced microwave dehydration by 10–20% (Torringa et al., 2001). In addition to this, Prothon et al. (2001) demonstrated, osmotically dried apple cubes in 50% (w/w) sucrose, and then dried them in a microwave-assisted drier reduced drying time required to reach 10% moisture.

As reported by Li and Ramaswamy (2006b) simultaneous microwave heating and OD have double fold advantages in accelerating the moisture lose and reduction of solid gain under immersion mode of apple cylinders in osmotic solution. Further, Azarpazhooh and Ramaswamy (2010) compared osmotic drying effect under different osmo-drying conditions: osmo-microwave drying under spray mode, osmo-microwave drying under immersion mode, conventional osmotic drying under spray and conventional osmotic drying under immersion modes at two sucrose concentration and temperature combinations (40oBrix/40°C and 50oBrix/50°C). The moisture lose under microwave spray mode was around 35% as compared to conventional spray and immersion drying methods having moisture lose of less than 12% after 30 min of drying.

Increase in power absorbed during microwave heating results to increase in the energy consumption rate per unit mass of water during microwave assisted drying. An equation for energy consumption rate per unit mass of water during microwave assisted intermittent power supply was proposed by Beaudry et al. (2003) and Yongsawatdigul and Gunasekaran, (1996). However it does not account for the energy supplied by hot air (Beaudry et al., 2003) and energy demand from the vacuum (Yongsawatdigul and Gunasekaran, 1996) during drying process. It was reported that higher power level (Drouzas and Schubert, 1996) and lower initial moisture content of osmotically treated food will yield better energy conservation.

In addition to microwave-convective drying, microwave-vacuum drying technology is investigated as an alternative method to reduce the cost and improve the food quality (Drouzas et al., 1999). The use of microwaves help us to overcome the common problem associated with poor heat transfer in vacuum drying. The dehydration rate for microwave-vacuum-drying is always faster and takes 33 min to dry carrot slices from 91.4 % to 10 % (wet
Yetenayet Bekele & Hosahalli Ramaswamy

base) with microwave-vacuum, as compared to 8 and 72 h with hot air and freeze-drying, respectively (Lin et al., 1998). The application of an osmotic treatment prior to microwave-vacuum drying combines the advantages of both unit operations in a unique way. Since no phase transition takes place in OD, energy consumption is especially low, even if the diluted solution needs to be concentrated by evaporation (Erle and Schubert, 2001). Based upon this, osmomicrowave-vacuum drying hybrid technology is used to produce dehydrated high quality products with reduced energy cost. This hybrid method creates food products with properties comparable to freeze drying, in shorter time and thus, at lower costs. In comparison to other advanced drying technologies (i.e. freeze drying) microwave vacuum drying is more economic, as drying progress is much faster and thus allows a higher throughput for the same plant dimensions (Ahrens et al., 2006).

Osmotic-vacuum drying

In vacuum drying method the food is subjected to a low pressure and simultaneous low heating source. The vacuum allows the water to vaporize at a lower temperature than at atmospheric conditions, thus foods can be dried without exposure to high temperature and low level of oxygen in the atmosphere diminishes oxidation reactions during drying. In general, color, texture, and flavor of vacuum or vacuum-freeze dried products are improved as compared with air-dried products.

Pressure driven flow is the major moisture removal mechanism from a food. Because of the need of creating reduced pressure in a drying chamber the technique is more expensive and often used as a secondary dryer. The duration of vacuum drying process mainly depends upon the level of moisture to be removed and level of reduced pressure maintained. The energy and reduced pressure demand to remove moisture from a food can be minimized by combining osmotic treatment before actual vacuum drying. This method mainly more advantageous for fruits and vegetables which are very rich in moisture, but OD can enable us to reduce the percentage of original moisture by 30-50%. For fruits with high water activity (aw) and high porosity, the application of OD with vacuum pressure found to be advantageous compared to atmospheric pressure drying process, (Mújica-Paz et al., 2003). Meanwhile Shi et al. (1995) evaluated the influence of vacuum treatment on mass transfer during OD of fruits, and they confirmed that OD under vacuum makes it possible to obtain a higher diffusion rate of water transfer at lower solution temperatures for fruits with high porosity. Beaudry et al. (2004) they compared four drying methods of drying (osmo-vacuum, osmo-microwave, osmo-freeze and osmo-convective) and found that the drying rate of osmo-vacuum treated cranberries is the higher following osmo-microwave drying method. Moreover reduction in pressure causes the expansion and escape of gas enclosed in the pores, and pores can be occupied by osmotic solution, thus increasing mass transfer rate (Rahman, 2007). The process strongly favors solute uptake through an effective increase of mass transfer surface, caused by replacement of gas in the pores with osmotic solution (Fito et al., 1994; Chiralt et al., 1999). Therefore the advantage of OD at vacuum pressures over atmospheric OD is that the solid–liquid interface area and the mass transfer between both phases can be increased (Fito et al., 2002). Hence the cumulative sum of the above benefits enhance rate of drying and rapid mass
transfer which have a significant effect in energy reduction process of osmo-vacuum drying method as compared to conventional vacuum drying.

CONCLUSIONS

Osmotic dehydration is a simultaneous mass transfer process which mainly promotes the flow out of water molecules from the food to osmo-active solution and some migration of solutes from the solution into the food. Different factors can influence the overall mass transfer kinetics during dehydration process. In the process the flux out of water from the product to the osmotic solution is by far greater than the solute gain and this result in partial dehydration of the product. Moisture content of fruits and vegetables are high (75-95%). Osmotic dehydration as an upstream partial dehydration process can reduce this moisture content by 30 to 50% for which energy in the form of latent heat need not be supplied. Subjecting a product to osmotic dehydration treatment on upper stream of the drying process therefore plays a significant role in terms of improving the energy use efficiency during drying process. In these days of political and economic arena, energy is the key issue and the cost of energy is escalating from time to time. Reduction of costs associated with energy is one means to maximize profit in both food and non food processing industries. For instance energy saving in drying industries by 1% could result as high as 10% increase in profit margin (Beedie, 1995). Osmotic soaking reduce exposure to oxidation degradation and partial dehydration as well as solute uptake by the product prevents structural collapse during subsequent drying process and hence, osmotically dehydrated products have better color, flavour, texture and taste as compared to untreated ones.

REFERENCES


Alibas, I. 2007 Microwave drying of apple pomace parameters of pumpkin slices, LWT-Food Science and Technology 40:1445-1451.


Yetenayet Bekele & Hosahalli Ramaswamy


McLoughlin, CM, McMinn, WAM and Magee, TRA. 2003. Microwave drying


Yetenayet Bekele & Hosahalli Ramaswamy


