

INFLUENCE OF DIFFERENT DRYING METHODS ON FRUITS' QUALITY

M.N.A. Hawlader, Associate Professor, Department of Mechanical Engineering,
National University of Singapore, Singapore*

*Conrad O Perera, Adjunct Associate Professor, Department of Chemistry,
National University of Singapore, Singapore*

*Min Tian, Research Scholar, Department of Mechanical Engineering,
National University of Singapore, Singapore*

**Corresponding Author Email: mpehawla@nus.edu.sg*

ABSTRACT

A low-energy-consuming drying process that produces high quality products is desirable in food industry. As heat pump dryer has a high Coefficient of Performance and could provide a satisfactory drying condition for heat-sensitive foods at a relatively low cost. Since the drying system operates in a closed loop, the air can be replaced by an inert gas to yield a modified atmosphere, thus eliminating oxygen, which causes most of the deteriorative quality changes in dried products due to oxidation. In this study, some temperature sensitive materials such as guava and papaya were dried in heat pump dryer using normal air, carbon dioxide and nitrogen. These materials were also dried in vacuum dryer and freeze dryer under similar conditions. The drying kinetics and quality of these dried fruits resulting from different drying methods were investigated and compared. The change of color, porosity, and loss of vitamin C were evaluated to identify the potential of modified atmosphere heat pump drying. Experiments showed that introducing inert gas as drying medium made much improvement of foods' quality, which led to a better physical appearance, quicker rehydration and better retention of nutrients.

Key Words: *Drying, heat pump, inert gases, drying kinetics, food quality.*

1 INTRODUCTION

Drying by dehumidification refers to a process in which moisture is removed from a solid using heat as the energy input. The mechanism of drying involves combined heat and mass transfer and, in most cases, changes the properties of products. It is obvious that drying itself is an energy-intensive process because the latent heat has to be supplied to the material to evaporate the moisture. Therefore, the goals of drying process research are three-fold:

e, the goals of drying process research are three-fold:

process research are three-fold:

ree-fold:

- ✧ Product quality: to avoid the undesirable changes and to produce the desired quality.
- ✧ Economic considerations: to balance the initial investment and running cost, making it operate at optimum conditions.
- ✧ Environmental concerns: to minimize energy consumption during drying and reduce the industry waste impact to environment.

Drying has found applications in a variety of industries, especially the lumber, agricultural and food processing sectors. Many technologies have been developed to achieve best products, such as hot air drying, vacuum drying and freeze drying. However, if taking all the three considerations mentioned earlier into account, it is generally agreed that heat pump drying is one of the most promising technologies. Their ability to convert the latent heat of vapor condensation into the sensible heat of an air stream passing through the condenser makes them attractive. Strømmen et al. (2003) found that heat pump dryers consume 60-80% lower energy than other dryers operating at the same temperature. For decades, it has been used in wood kilns to dehumidify air and control lumber quality

(Rosen 1995). A great number of heat pumps are installed in Finland, Norway and Canada for drying of wood and fish (Strømmen and Kramer 1994).

The current trend relates to the development of improved drying process for heat sensitive food and biological material drying. In many agricultural countries, large quantities of food products are dried to improve shelf-life, reduce packaging costs, lower shipping weights, enhance appearance, encapsulate original flavor and maintain nutritional value (Sokhansanj and Jayas 1987). It is because that a food loses its moisture content after drying, which results in increasing the concentration of nutrients in the remaining mass. Proteins, fats and carbohydrates are present in larger amounts per unit weight in dried food than in their fresh counterpart. As the mechanism of drying is very complex, it results in modified quality of products sometimes. Some of them are undesirable, such as browning, shrinkage, loss of nutrients and so on.

Rossi et al. (1992) reported that onion slices dried by heat pump dryer (HPD) led to an energy saving of the order of 30% with better product quality. Recently, by substituting the normal air in closed HPD with certain inert gas, O'Neill et al. (1998) noted that dried apple cubes resulted in porous products, leading to quick rehydration. Perera (2001) observed that dried apples showed excellent color, retention of vitamin C and the overall quality of the dried product. Halawder et al. (2004) found not only color but also improved rehydration ability of dried products. From the results of these research, modified air heat pump drying (MAHPD) seems to own a great potential in this area, but the relative researches are scarce and the material used were mainly apples.

Hence, a lack of information exists in other heat-sensitive materials. In order to provide a better understanding and have a clearer insight, both the drying kinetics and quality of guava and papaya dried in different gas were studied extensively in this investigation. The results of quality tests were also compared with those of freeze drying and vacuum drying samples.

2 DRYING KINETICS

In the existing literatures (Mujumdar and Menson 1995; van Arsdel and Copley 1963), a generalized drying rate curve includes a constant drying rate followed by falling rate regions. Crank (1975) thought if only radial diffusion is considered and neglect the effects of temperature and total pressure gradients, Fick's second law of the unsteady state diffusion could describe the transport of water during food dehydration process. Considering the sample cube as a flat plate of thickness L , drying on both sides and under the given boundary conditions of

$$t = 0; 0 \leq x \leq L; M(t) = M_0$$

$$t > 0; x = 0, L; M(t) = M_{eq}$$

the following solution exists in the absence of any external resistances (Rao and Rizvi 1986)

$$MR = \frac{M(t) - M_{eq}}{M_0 - M_{eq}} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp\left[-(2n-1)^2 \pi^2 \frac{Dt}{L^2}\right] \quad (1)$$

Where MR is moisture ratio of free water still to be removed at time t to the total free water initially available, and $n=1, 2, 3 \dots$ the number of terms taken into consideration.

This solution is applied to thin-layer drying of different foods by a great number of researchers (Jayas et al. 1991; Vaccarezza and Chirife 1978). For a long time drying, where equilibrium moisture is attained, the higher order terms are neglected by setting $n=1$. Hence, the Eq. (1) could be further simplified to a linear form:

$$\ln(MR) = \ln\left(\frac{M(t) - M_{eq}}{M_0 - M_{eq}}\right) = \ln\left(\frac{8}{\pi^2}\right) - (D \frac{\pi^2 t}{L^2}) \quad (2)$$

Shrinkage of the material is neglected, so L is a constant during the whole process. As a consequence, the effective diffusivity, which incorporates factors that were not considered separately but would affect the drying characteristics, can be determined by plotting experimental drying data in the form of (MR) versus time. In this study, the drying kinetics of fruits is investigated under controlled laboratory conditions. This simple equation was applied to fit the drying data by non-linear regression to evaluate the influence of inert gas on the diffusivity quantitatively.

3 MATERIAL AND METHODS

Guava and papaya are typical tropical fruits, which could be bought easily in Singapore. They are rich in vitamin C. And the tissue structure is different: guava is hard while papaya is soft. Because of these characteristics, they are chosen to conduct experiments. The material were cut into $1\text{cm} \times 1\text{cm} \times 1\text{cm}$ cube before experiments.

A lab heat pump dryer, shown in Fig. 1, was used in the experiment, which operates in a closed loop. About 100 grams samples were fed in each experiment. When using inert gas, the chamber was evacuated firstly before nitrogen or carbon dioxide was pumped in. This procedure was repeated three times at the beginning of each experiment, making sure that the normal air was substituted as completely as possible. The drying temperature inside the chamber was measured by type T thermocouple with the accuracy of $\pm 0.1^\circ\text{C}$, which is inserted in the middle position of the inlet cross section. The air velocity was measured in advance and set at a fix value. A humidity sensor was used to measure the relative humidity. The weight of the samples was continuously monitored by a load cell. All the data were collected by HP 34970A data logger and downloaded to a personal computer. In the stable stage, a relative humidity (RH) of around 10%, air velocity of 0.7m/s and temperature around 45°C were maintained in the drying chamber. The drying time was 8 hours.

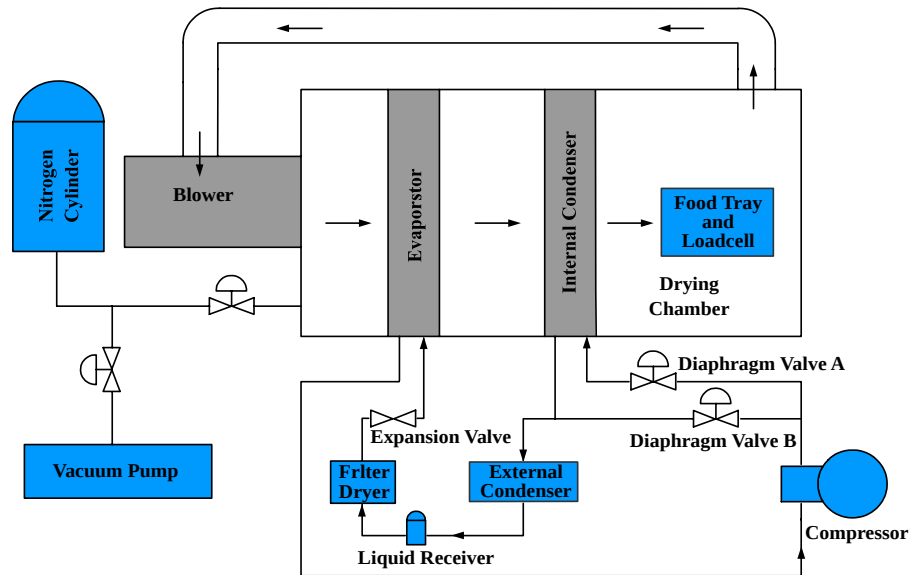


Fig. 1. Schematic diagram of MAHPD

For freeze drying, the samples were first placed in a fridge at a temperature of -20°C for 24 hours. The moisture in the cubes was frozen to form solid ice during this period. Then the frozen samples were dried under the condition of which the pressure is below 4.6mm/Hg and temperature is 10°C in average for 24 hours.

Vacuum drying is a drying method in which drying is performed using low pressure. It makes use of the fact that the boiling point of water is reduced as the pressure is reduced (Krokida and Maroulis 2000). In this study, the drying was performed at a pressure of 0.15 bar and a temperature of 45°C for 24 hours.

All the samples were stored in a vacuum desiccator with silica gels at the bottom to get a bone dry mass before quality tests. It took about 10 days. During this period, the weight was monitored regularly until the difference between recent two consecutive recordings did not vary by more than 0.1 gram .

CIE (Commission International de l'Eclairage) color values were measured using the Minolta CM-3500d Spectrophotometer. For each cube the lightness (L), redness (a), and yellowness (b) were captured for 5 randomly selected samples of each batch. Total color change DE^* is calculated and compared, which is defined as

$$DE^* = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

differences are compared with their fresh counterparts.

The Scanning Electron Microscope (SEM) JSM-5600LV was used to investigate the surface porosity of the dried food samples. SEM captured detailed 3-dimensional images at much high magnifications ranging from 15 to 200,000 times with a resolution of 5 nanometers. In this study, the magnification was restricted at 100 times.

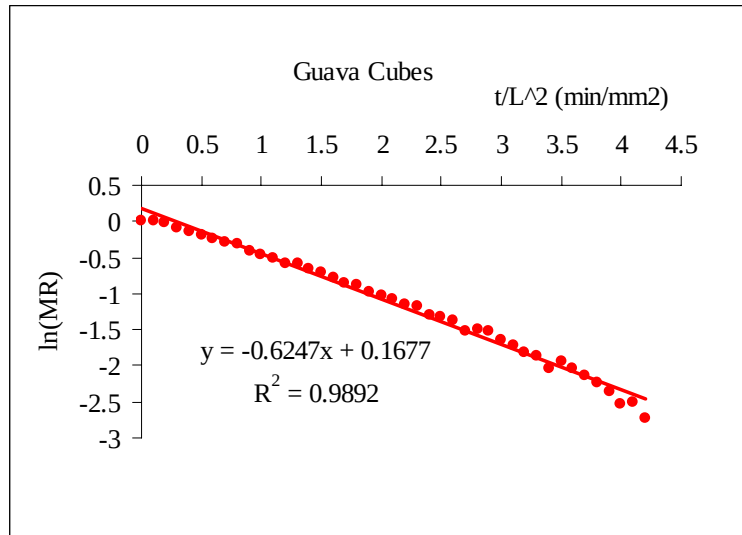
Vitamin C test adopted indophenol method (using Tillman's reagent-titration or photometric): titrate indophenol solution (16.2mg/L), monitoring color changes due to 2, 6-dichloroindophenol reduction, which is recommended by AOAC(1984). The concentration in fresh fruits was set to 100 percent compared with that in their dried counterparts.

4 RESULTS AND DISCUSSION

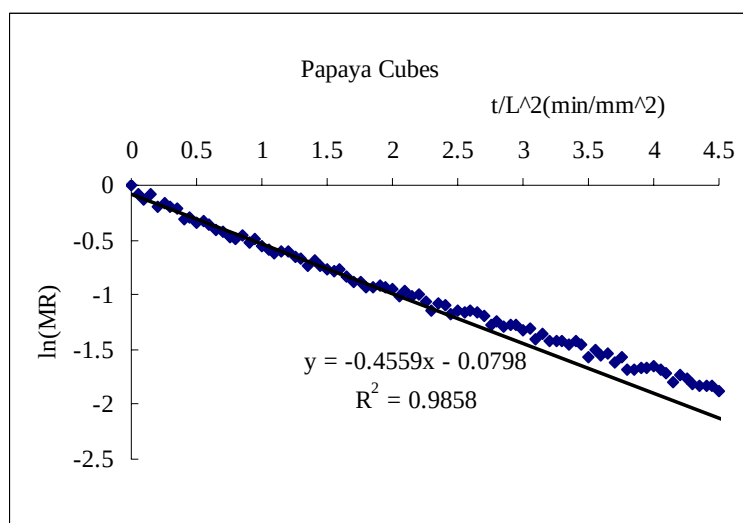
All the results of experiments showed that both the drying kinetics and quality of dried products were improved when using inert gas instead of normal air in heat pump dryer. Some of them even better than vacuum dried and freeze dried samples.

4.1 Drying Kinetics

In this experiment, only falling rate periods exist in the drying curve, as the drying of heat sensitive material is consider a slow process. The diffusivity of guava and papaya in MAHPD using different gas were calculated according to equation (2), assuming the thickness L is constant throughout the drying process. In Fig. 2, the experimental values of $\ln(MR)$ for nitrogen drying were plotted against t/L^2 . The slope of the curve is a measure of the effective diffusivity. All other curves of guava and papaya had a similar form. In Fig. 2 (a), the variation nearly follows a straight line. Therefore, it was considered that the drying of guava took place in one falling rate period, which means that the liquid diffusion is the main driving force controlling the whole drying process. However, it is slightly different for papaya drying. The discrete points tilt a bit at x value about 2.5. This point was considered to be the beginning of second falling rate periods, from which the effective diffusivity dropped a little. This difference may be due to the different micro structure of material. It was observed that the drying of papaya cubes led to a case hardening while there was no such phenomenon observed when drying of guava. The case hardening prevented the moisture transfer to the hot air, resulting in a slowing transfer rate.



(a)



(b)

Fig. 2. Variation of $\ln(MR)$ with t/L^2 (a) Guava; (b) Papaya

The results of other drying methods are summarized in Table 1, including correlation coefficients (R^2). From these data, it can be found that nitrogen drying has the highest effective diffusivity, followed by carbon dioxide drying, while normal air drying yields the lowest. The possible reason is the physical properties of different gas. For nitrogen, the specific heat ($1.04 \text{ kJ/kg} \cdot ^\circ\text{C}$) is higher than that of normal air ($1.00 \text{ kJ/kg} \cdot ^\circ\text{C}$) while their densities are nearly the same ($0.9737:1$). Hence, their masses are same at same volume. In fixed volume system, nitrogen could absorb more heat from the heat exchanger and release more when passing the samples in the chamber. For carbon dioxide, though the specific heat ($0.85 \text{ kJ/kg} \cdot ^\circ\text{C}$) is lower while its density is much higher ($1.539:1$), there is larger mass at fixed volume. It also owns a larger heat transfer capability.

Table 1. Diffusivity of Guava and Papaya in MAHPD

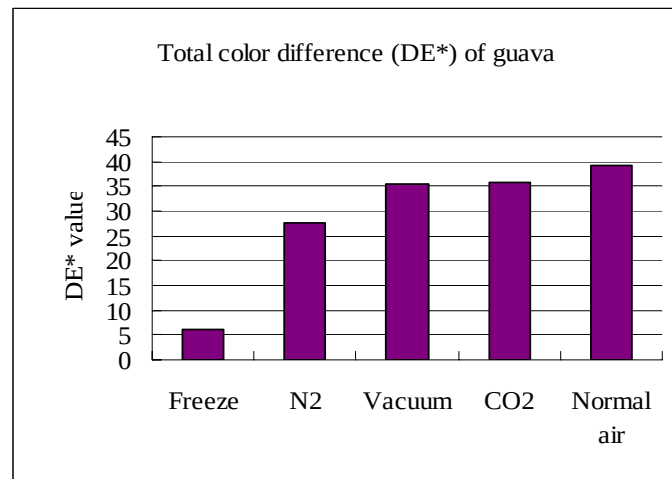
Material	Drying Medium	Effective Diffusivity ($\times 10^{10} \text{ m}^2 / \text{s}$)	R^2
Guava	Normal Air	6.09	0.9926
	Nitrogen	10.55	0.9892
	Carbon Dioxide	8.79	0.9932
Papaya	Normal Air	6.61	0.9943
	Nitrogen	7.69	0.9858
	Carbon Dioxide	7.53	0.9936

4.2 Color

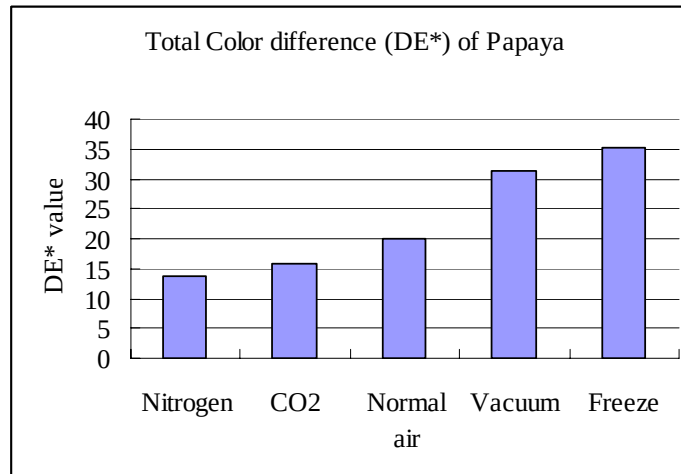
Usually, thermal process changes the original color of products, especially for foods like fruits and vegetables which consist of much water, carbohydrate, protein and fractions of lipids. These compounds are easily modified in the high temperature drying condition and result in degradation in food quality (Sokhansanj and Jayas 1987).

The total color change of dried guava and papaya resulting from 5 drying methods is shown in Fig. 3. From both Fig. 3(a) and 3(b), it is clear that inert gas have a smaller color change than normal air. It is known that enzymic browning requires four different components: oxygen, enzyme, copper and a substrate (Langdon 1987). Hence, a reduction of oxygen content in the drying chamber could improve the color. Normal air consists of 20% oxygen in volume while that in inert gas for this experiment is much lower. This result is consistent with the previous study (Halawder et al. 2004). It is also noted that, for guava, the nitrogen dried products are even better than vacuum dried. Freeze

drying gave the smallest change. In contrast, for papaya, the DE* of freeze drying is the largest. The possible reason is that freeze drying increased the lightness (L*) too much for papaya which is dark color fruit while guava is light color. Hence, compared with their original color, freeze dried papaya seemed far light, which was not desirable.



(a)



(b)

Fig. 3. Total color change: (a) Guava; (b) Papaya

4.3 Porosity

Porosity characterizes the overall open structure of a dehydrated material and is strongly affected by the material moisture content, drying method and conditions (Krokida and Maroulis 2000). SEM pictures can reflect the micro porosity clearly. The dark area stands for the open pore on the surface. From Fig. 4, it can be clearly seen that the surface pores of freeze dried papaya (Fig. 4(a)) is much more than that of any other method, and the size is also larger. When normal air dried sample (Fig. 4 (b)) is compared with inert gas dried one (Fig. 4(c) and 4(d)), the phenomenon that the surface of MAHPD dried products were more uneven was observed. It could be concluded that they are more porous than those of normal air drying. The possible reason suggested by some researchers is the complex interaction of wound response and hypoxia under inert gas atmosphere (O'Neill et al. 1998). For vacuum dried papaya (Fig. 4(e)), a puff effect was observed; there were bubbles under the hard shell. Reduced pressure may have been a contributing factor.

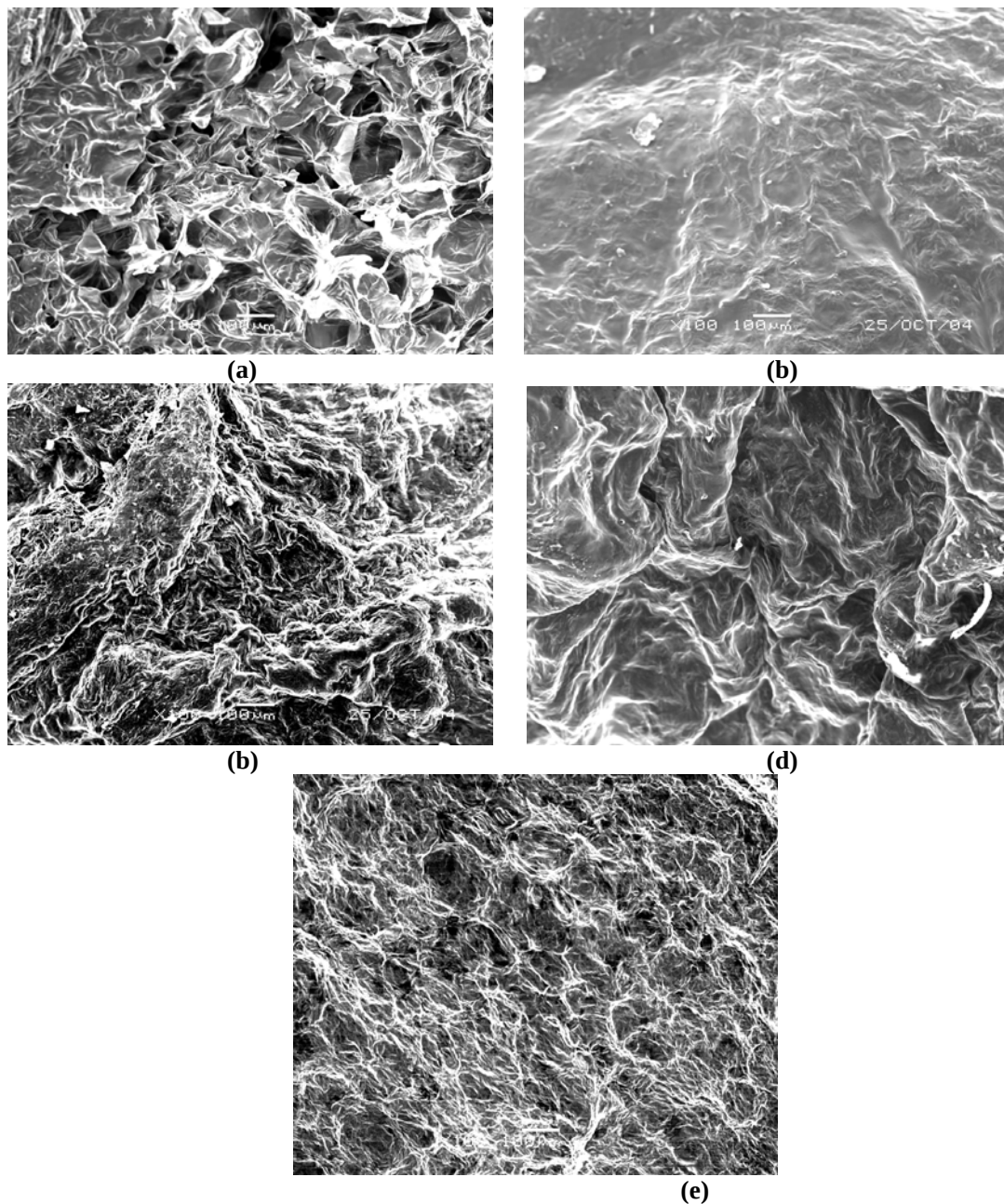


Fig. 4. SEM of dried papaya: (a) freeze drying; (b) normal air drying; (c) carbon dioxide drying; (d) nitrogen drying; (e) vacuum drying.

4.4 Vitamin C

Fresh fruits are rich sources of vitamin A and C besides minerals, which are the important supply for human body. Because of their perishable characteristic, it is desired to store a long time with minimum loss of nutrients (Jayaraman and Das Gupta 1999). The present study showed that, as indicated in Table 2, freeze drying retained the most vitamin C in both papaya and guava (88% and 63%, respectively), and then vacuum drying is the second. Compared with normal air, carbon dioxide and nitrogen have better retention. The improvements are considerably great, though they are different in guava and papaya. It is because of the fact that the retention of vitamins depends on the nature of foods (Jayaraman and Das Gupta 1995).

As vitamin C is easy to deteriorate in oxidative atmosphere, the first reason for the improvement in inert gas is that it reduced oxidation. Temperature also affects vitamin C. Hence, freeze drying has the best results since it is a low-temperature drying process. However, products

retained slightly more vitamin C resulting from carbon dioxide drying, 82% versus 80% and 41% versus 39%. The possible reason is that nitrogen drying has a higher rate than carbon dioxide drying. Hence, the higher rate of drying resulted in an increased loss of vitamin C .

Table 2. Retention of Vitamin C in dried products

Material	Drying methods				
	Normal Air	CO2	N2	Freeze	Vacuum
Papaya	75%	82%	80%	88%	86%
Guava	25%	41%	39%	63%	58%

5 CONCLUSIONS

As discussed earlier, the MAHPD improved not only drying kinetics but also quality of dried products. By using inert gas as the drying medium, it reduces the oxygen content significantly, which causes most of the deteriorative quality changes. Experiments showed that it led to a better physical appearance, quicker rehydration and better retention of nutrients. For guava, the improvement, when adopting MAHPD, in color is 29.8%, in porosity is 82.5%, and in vitamin C retention is 64%. Some quality is even comparable with the freeze drying samples, which is thought to be the best way and also the most expensive to improve products quality. Since MAHPD could yield acceptable products quality at a relative low cost, it has shown great potential in the area drying sensitive material.

ACKNOWLEDGMENTS

The authors wish to acknowledge the help received from Mr. Yeo Kianliang in collecting experimental data, Madam Zhong Xiangli in helping use SEM and Mr. Shang zhenghua in helping using mercury porosity meter during this project.

REFERENCES

- AOAC 1984, "Vitamins and other nutrients," In *Official Methods of Analysis of the Association of Official Analytical Chemists*, 14th Edition (Willim S, ed.), AOAC, Virginia; pp. 838-841.
- Bourne M. C. 2002. *Food Texture and viscosity second edition: Concept and measurement* (2nd ed.). Academic Press, New York, pp.400
- Crank J. 1975, *Mathematics of diffusion* (2nd ed.). Oxford University Press, London.
- Hawladar M.N.A, Perera C.O., Tian M. and Chng, K. J. 2004, "The properties of modified atmosphere heat pump dried foods," *Drying 2004, Proc of the 14th International Drying Symposium (IDS 2004)*, Sao Paulo, Brazil, 22-25 Aug 2004, Vol. A, pp. 309-316.
- Jayas D. S., Cenkowski S. Pabis S. and Muir W. E. 1991, "Review of the thin-layer drying and wetting equations," *Drying Technology*, Vol. 15, pp.183-199.
- Jayaraman K.S. and Das Gupta D.K. 1995, "Drying of fruits and vegetables," In Mujumdar, A. S. (Ed.), *Handbook of Industrial Drying*, Marcel Dekker, Inc., pp.643-690.
- Langdon T.T. 1987, "Preventing browning in fresh prepared potatoes without the use of sulfiting agents," *Food Technology*, Vol.41, pp.64-72.

- O' Neill M. B., Rahman M. S., Perera C. O., Smith B. and Melton L. D. 1998, "Colour and density of apple cubes dried in air and modified atmosphere," *International Journal of Food Properties*, Vol.1, pp.197-205.
- Perera C. O. 2001, "Modified atmosphere heat pump drying of food products," *Proc. 2nd Asia-Oceania Drying Conference (ADC' 01)*, Edited by Daud et al., pp.469-476.
- Lewis M. J. 1987, *Physical Properties of Foods and Food Processing Systems*, Chichester: Ellis Horwood Ltd. pp. 51-68.
- Mujumdar, A. S., Alves-Filho, O., "Drying Research-Current State and Future Trends," *13th International Drying Symposium*, Beijing, China, 27-30 Aug, KNL-01.
- Rahman S. 1995, "Physical properties of food," In *Food Properties Handbook*, CRC Press, Boca Raton, pp. 179-224.
- Rahman M. S., Perera C. O., Chen X. D., Driscoll R. H., and Potluri P. L. 1996, "Density, shrinkage and porosity of calamari mantle meat during air drying in a cabinet dryer as a function of water content," *Journal of Food Engineering*, Vol. 30, pp. 135-145.
- Rao, M. A., Rizvi, S. S. H., In *Engineering Properties of Foods*. Marcel Dekker, Inc., pp.133-214.
- Rosen H.N. 1995, "Drying of wood and wood products," In Mujumdar, A. S. (Ed.), *Handbook of Industrial Drying*, Marcel Dekker, Inc., pp.683-710.
- Rossi S. J., Neues I. C., and Kicokbusch T. G. 1992, "Thermodynamics and energetic evaluation of a heat pump applied to drying of vegetables," In Mujumdar A. S. (Ed.), *Drying 92*, Amsterdam: Elsevier Science, pp.1475-1483.
- Schubert H. 1987, "Food particle technology, Part I: properties of particles and particulate food systems", *Journal of Food Science*, Vol. 41, pp. 1189-1193.
- Sokhansanj S. and Jayas D. S. 1987, "Drying of foodstuffs," In Mujumdar, A. S. (Ed.), *Handbook of Industrial Drying*, Marcel Dekker, New York, pp.517-554.
- Strømme I. and Kramer K. 1994, "New applications of heat pumps in drying processes," *Drying Technology*, Vol.12, pp.889-901.
- Strømme I., Eikevik T. M., Alves-Filho O., Syverud K. and Jonassen O. 2002, "Low temperature drying with Heat Pumps - new generations of high quality dried products," *13th International Drying Symposium (IDS 2002)*, 27-30 Aug, Beijing, China, KNL-02.
- Van Arsdel W.B. and Copley M. J. 1963, *Food Dehydration*, AVI publishing, Westport, Connecticut.
- Vaccarezza L.M. and Chirife J. 1978, "On the application of Fick's law for the kinetic analysis of air drying of food," *Journal of Food Science*, Vol. 43, pp.236-238
- Zogzas N.P., Maroulis Z.B. and Marinos-Kouris D. 1994, "Density, shrink *Drying Technology*, Vol. 12, pp. 1653-1666.