HEAT PUMP ATMOSPHERIC FREEZE-DRYING OF GREEN PEAS

Pablo García-Pascual[1], Odilio Alves-Filho[2], Ingvald Strømmen[3] and Trygve M. Eikevik[2]
1. PhD Student & fellow at the Marie Curie Training Site in Drying at NTNU-SINTEF
email: Pablo.Garcia@maskin.ntnu.no
2. SINTEF Energy Research, N-7465 Trondheim, Norway
email: odilio.alves@sintef.no
email: Trygve.m.Eikevik@sintef.no
3. Norwegian University of Science and Technology, N-7491 Trondheim, Norway
email: ingvald.strommen@kkt.ntnu.no

Keywords: Colour, density, floatability, property, quality, rehydration, water activity

ABSTRACT

The drying of green peas was studied in a fluidised bed heat pump dryer under normal and atmospheric freeze-drying conditions. Three types of green peas and two bed heights were used in the drying trials, operating either in isothermal conditions or on a combination of temperatures. The evolution of the moisture content was recorded and different quality parameters were measured before, during or at the end of the drying process. This included colour, water activity, floatability, bulk density and rehydration. The results show that the atmospheric freeze-drying permits to obtain dried samples with high quality sensory properties. Drying kinetics were modelled with a diffusion model, and the effect of temperature on the effective diffusion coefficient follows the Arrhenius relationship. The activation energy values were 5046 and about 5910 kJ kg^{-1} for 8 mm and 10 mm diameter samples, respectively.

INTRODUCTION

Nowadays there is a challenge to obtain high quality products. According to Achanta and Okos (1996), dried products should accomplish the three following requirements:

1. To have a high quality properties that satisfies the consumers
2. To have a low production cost.
3. To have a low environmental impact.

These requirements can be fulfilled by heat pump atmospheric freeze-dryers (HPAFD), which if properly designed can use only a fraction of the usual energy consumption by conventionally dryers with similar capacity. Also, the HPAFD allows maintaining the quality and properties of the materials such as colour,

density of rehydration ability. The drying loop is closed and natural fluids are used as the new CO2 HP dryer built recently at NTNU-SINTEF.
Studies about the dehydration of green peas have been carried out in the past (Simal et al., 1996), but new experimental tests are needed to obtain data on the application of the HPAFD to study the operating effects on properties and quality.
Diffusion is among the models used to describe the drying of foodstuffs, considering vegetables and fruits Water transport from the surface to the centre of the solid is driven by diffusion, following the Fick's second law. Depending on the assumptions the equation may be solved analytical or numerically, such as finite differences or finite element methods (Crank 1975, Alves-Filho 1984, Mulet 1994, Simal et al. 1996).
The goals of the present work are to describe the tests performed on heat pump atmospheric freeze-drying green peas and related results on properties and quality.

MATERIALS AND METHODS

With an initial moisture content of 73% wet basis (w.b.), the Green peas (*Pisum sativum*) were obtained locally and divided in 21 lots and placed in a freezer at -20 prior its use. Three different types of green peas with two diameters (8 and 10 mm) and different hardness were used in the trials. Drying experiments were performed in a HPAFD using two different bed heights and different temperatures as given in table 1.

Table 1. Experimental freeze and medium temperature drying data

Peas	Diameter, mm	Bed height, L	T, ºC
PP	8	2	-10 / +25
PP	8	2	-5 / +25
PP	8	4	-10 / +25
PP	8	4	-5 / +25
PP	8	2	-10
PP	8	2	-5
PP	8	2	+25
110-120 TM	10	2	-10 / +25
110-120 TM	10	2	-5 / +25
110-120 TM	10	4	-10 / +25
110-120 TM	10	4	-5 / +25
110-120 TM	10	2	-10
110-120 TM	10	2	-5
110-120 TM	10	2	+25
120-130 TM	10	2	-10 / +25
120-130 TM	10	2	-5 / +25
120-130 TM	10	4	-10 / +25
120-130 TM	10	4	-5 / +25
120-130 TM	10	2	-10
120-130 TM	10	2	-5
120-130 TM	10	2	+25

The heat pump dryer used to carry out the experiments has closed circuits, both for the fluid and for the drying air. All relevant parts of the HPAFD were insulated to avoid heat losses and the main components are an evaporator, a reciprocating compressor, two condensers, 3-way valve, liquid receiver,

throttling valve, piping and valves. The drying circuit has a centrifugal blower, a removable drying chamber, a cooler, a heater, a cyclone, piping, fittings and valves.
The drying chamber is cylindrical, 0.24 m in diameter and 0.5 m in height. Sensors placed at different points of the heat pump dryer allow monitoring and record of energy component inlet-outlet conditions. These sensors were connected to a Fluke hydra data logger and a PC in which experimental data were continuously stored.
The green peas drying kinetics were obtained in a fluidised bed mode batch. The air velocity was adjusted to reach good fluidisation. The sample moisture contents were measured using a Mettler LP16-PM200 infrared moisture meter.

Quality parameters

The water activity was measured in specific time intervals and at about 24ºC during the drying test with an Aqualab water activity meter, model CX-2 (Decagon Devices).
The colour was determined using an X-Rite 948 Spectrocolorimeter with a CIE 1964 10º observer and the illuminant D_{65}.
The floatability was assessed by placing a sample of a hundred peas into a kettle with water at 98ºC and by simply counting the floaters.
The standard method was used to determinate each sample the bulk density defined as total mass of the samples per volume, which includes the voids and particles.
Rehydration was measured by placing a sample of 1 g in water at 98ºC for 5 minutes, weighing the samples at the beginning and at the end of the test. The results were expressed as rehydration ability, which is given by:

$$r_a = \frac{\text{water content after rehydration}}{\text{dry matter of the product}} \tag{1}$$

Mathematical model

The Fick’s second law describes the water diffusion from the surface to the centre of a porous solid by:

$$\frac{\partial W}{\partial t} = -D_e\left(\frac{\partial^2 W_l}{\partial r^2} + \frac{2}{r}\frac{\partial W_l}{\partial r}\right) \tag{2}$$

This equation is solved considering the following assumptions: radial diffusion, a uniform initial moisture distribution, negligible external resistance to heat and mass transfer, a constant effective diffusivity and no shrinkage. In such a way the amount diffusing substance entering or leaving a sphere is given by the transport equation (Crank 1975, Alves-Filho 1984, Simal et al. 1996, Vázquez et al. 2000):

$$W = W_e + (W_0 - W_e)\sum_{n=1}^{\infty}\frac{6}{(n\pi)^2}\exp\left(\frac{-(n\pi)^2 D_e t}{r^2}\right) \tag{3}$$

In order to take into account the necessary number of terms of the series, thirty terms were used in the calculations. The parameters of the model were estimated by nonlinear least squares (Sen and Srivastava 1990). The accuracy or goodness of fit of the solution to the experimental data was explained by the explained variance (VAR) in accordance to Sen and Srivastava (1990). It represents the relative variance explained by the model with respect to the total variance and it varies from 0 to 100. The expression for VAR is:

$$VAR = 100\left[1 - \frac{S_{yx}^2}{S_y^2}\right] \quad (4)$$

For isothermal test conditions, the effective diffusivity (D_e) is assumed to vary only with air inlet temperature according to Arrhenius equation:

$$D_e = D_0 \exp\left(-\frac{E_a}{RT}\right) \quad (5)$$

RESULTS AND DISCUSSION

Drying curves

Figure 1 shows the drying curves for green peas of 8 mm diameter and volume of 2 liters bed height.

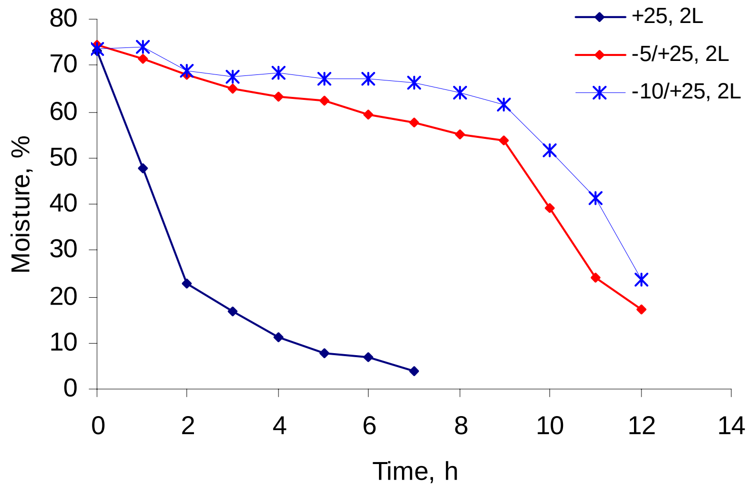

Figure 1. Drying curves for 8 mm peas and 2 L bed height

It can be observed in Figure 1 that the kinetics under freeze-drying conditions or during the first 9 hours are much lower than at 25ºC in which there is a sharply drop. Kinetics at 25ºC follows the typical trend for positive temperatures and the same patterns are observed for the rest of trials.

There were small differences among the three kind of green peas but the kinetics for the 8 mm peas, smallest diameter, were slightly faster as observed in Figure 2.

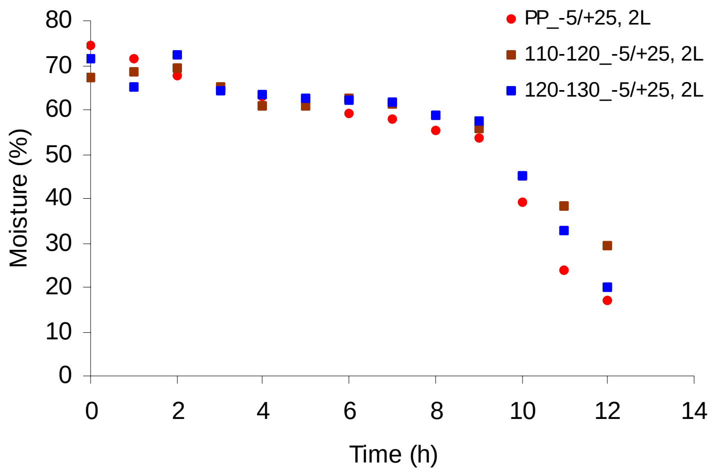

Figure 2. Drying curves for 8 mm peas and 2 L bed height

The diffusion expressed by equation (3) was used to describe experimental data for spherical green peas. Table 2 shows the inlet temperature in the tests and the equation parameter.

Table 2. Estimations of diffusion coefficients for isothermal conditions

Peas	Diameter, mm	T, ºC	D_e, $m^2\ s^{-1}$	VAR, %
PP	8	-10	$9.53\ 10^{-13}$	89.7
PP	8	-5	$3.59\ 10^{-12}$	86.9
PP	8	25	$1.53\ 10^{-10}$	95.4
110-120 TM	10	-10	$6.30\ 10^{-13}$	43.3
110-120 TM	10	-5	$1.95\ 10^{-12}$	80.3
110-120 TM	10	25	$2.12\ 10^{-10}$	94.2
120-130 TM	10	-10	$4.68\ 10^{-13}$	57.8
120-130 TM	10	-5	$3.06\ 10^{-12}$	86.5
120-130 TM	10	25	$1.98\ 10^{-10}$	95.4

It is observed from the data in Table 2 that the small diameter samples dry slightly faster than the others. The Arrhenius equation (Eq. 5) was used to describe the effect of temperature on the kinetic parameters of the model represented by the effective diffusion coefficient D_e. The activation energy indicates the effect of temperature on the rate of moisture sorption. Table 3 shows the calculated activation energy for the three samples.

Table 3. Parameters of the Arrhenius relationship (Eq. 5)

Sample	Pre-exponential factor (D_0)	Activation Energy
PP (8 mm)	$1.36\ 10^{6}$	5046 kJ kg^{-1}
110-120 TM (10 mm)	$1.18\ 10^{5}$	5937 kJ kg^{-1}
120-130 TM (10 mm)	$7.88\ 10^{5}$	5882 kJ kg^{-1}

Both samples with 10 mm diameter required similar amounts of energy to remove one kg of water, which suggest that the green peas hardness has no significant effect on activation energy or kinetics. However, the samples of 8 mm require less energy, with a consequent faster rate of water removal. This can also be observed in Figure 3, where Ln(D_e) is plotted against the inverse of the absolute air-drying temperature.

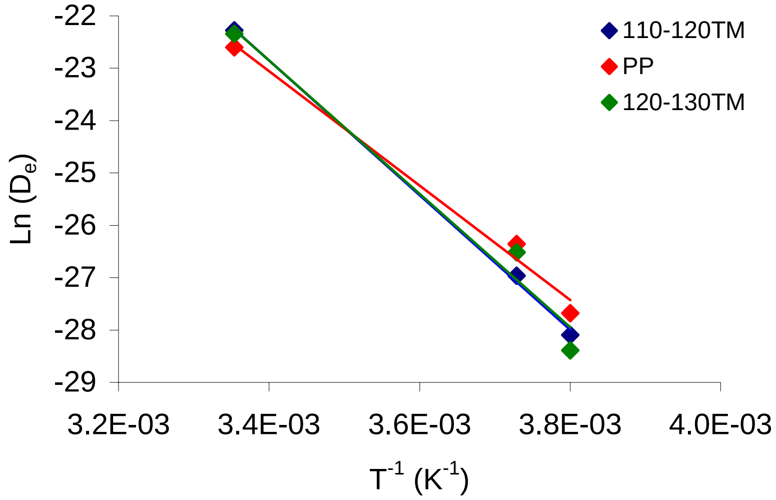

Figure 3. Effect of rehydration temperature on diffusion coefficient

Simal et al. (1996) obtained an E_a value for drying of green peas of 1371 kJ kg^{-1}, a lower value because they exposed the peas to blanching before drying and also the samples were dried at higher temperatures.

Quality parameters

The experimental water activity data for the 8 mm diameter peas are plotted in Figure 4. The minimum value was 0.64 when the lowest sample moisture content was 3.8% w.b. The measurements for the other two samples followed the same trend.

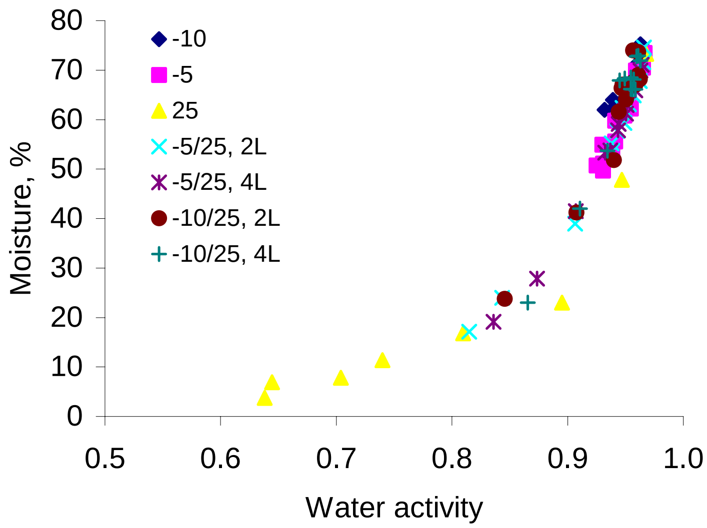

Figure 4. Effect of rehydration temperature on diffusion coefficient

The colour main variations occurred in the parameters a* and b*. Figure 5 shows the colour change of samples being dried at different temperatures.

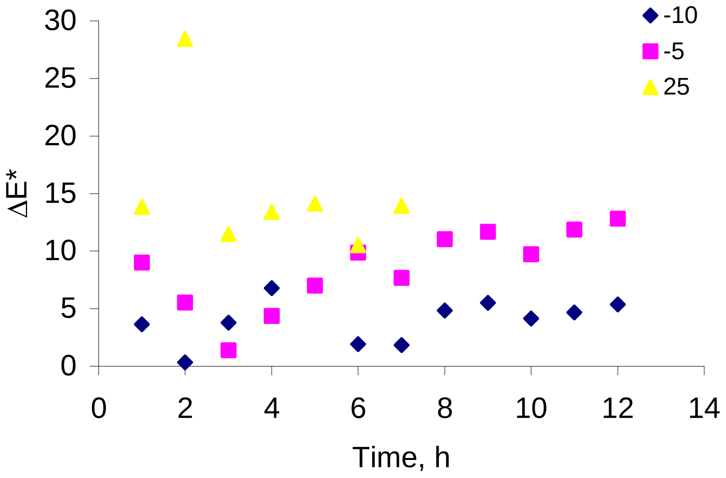

Figure 5. Change in colour for 8 mm diameter peas dried at three different temperatures

The sample colour varied between 0.3 and 7.0 for -10ºC and the change was higher for -5ºC than for -10ºC. The difference in colour was much larger when the air temperature was increased to 25ºC and bed height had no effect on the colour change. The other samples followed the same trend.

The bulk density was higher for the fresh peas and decreased for dried products as observed in Figure 6. The higher value for the sample dried at 25ºC is explained because this condition caused higher shrinkage or decrease in particle volume. The same pattern was found for the other two samples.

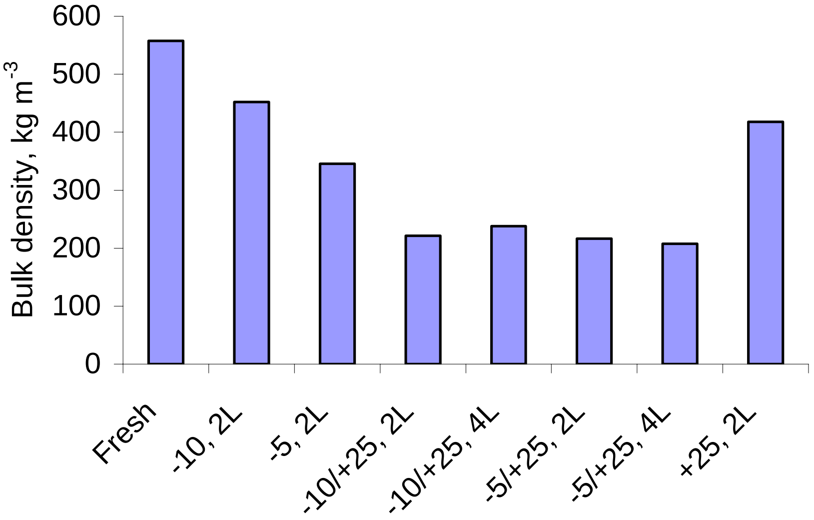

Figure 6. Variation of bulk density in peas of 8 mm diameter

The samples totally or partially freeze-dried preserved the structure and the volume. Consequently, the number of floating particles varied around 98 and 100%. However, the samples dried at isothermal and positive temperature (25ºC) had lower number of floaters, due to the shrinkage of the product and the higher density of the material.

The rehydration ability r_a was higher for samples fully dried under freeze-drying conditions, as it observed in Figure 7 for peas of 8 mm diameter; all others had similar values for rehydration. The same trend was observed in the other two samples.

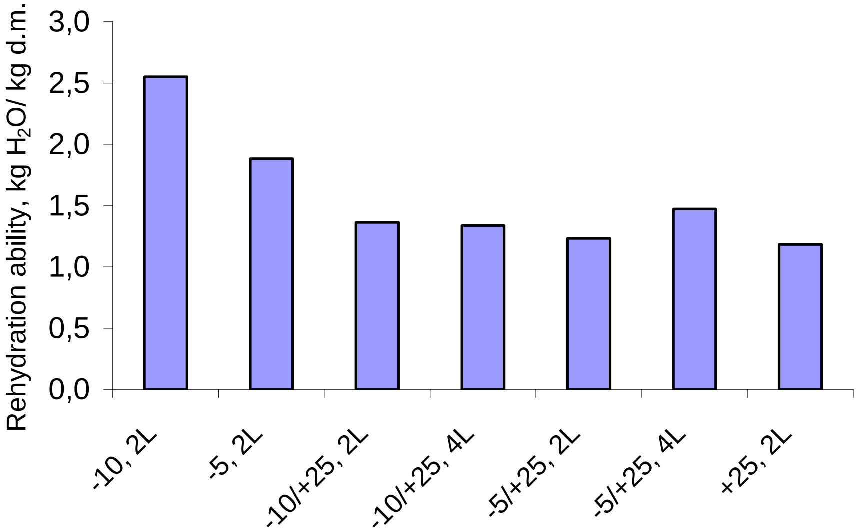

Figure 7. Rehydration ability in peas of 8 mm diameter

CONCLUSIONS

Several experimental HP drying runs were done with green peas at different drying conditions. The drying curves and relevant physical properties such as isotherm, colour, bulk density, floatability and rehydration ability were monitored or recorded during the trials.

The results show that the drying rate is higher for peas with lower diameter but there is no effect of material hardness on the drying kinetics. Experimental data were described by a diffusion model for a sphere. Effective diffusion coefficients were related with temperature using the Arrhenius equation. The values of activation energy were 5046 kJ kg^{-1} for 8 mm diameter samples and about 5910 kJ kg^{-1} for samples with 10 mm diameter.

The higher the temperature causes higher change in colour. Freeze-dried products maintained a better structure, yielding lower bulk density, and higher values of floatability and rehydration compared to samples dried at positive temperatures.

ACKNOWLEDGMENT

The authors acknowledge the support from the European Community under the programme Marie Curie Training Site and contract number HPMT-CT-2001-00304.

NOTATION

a^*	Chromacity coordinate of the L*a*b* colour space	Dimensionless
b^*	Chromacity coordinate of the L*a*b* colour space	Dimensionless
D_e	Effective diffusion coefficient	$m^2\ s^{-1}$
D_0	Diffusion pre-exponential factor	$m^2\ s^{-1}$
d.m.	Dry matter	kg
ΔE^*	Colour difference in the L*a*b* colour space	Dimensionless
Ea	Activation energy	$kJ\ kg^{-1}$
r	Radius of the sphere	m
R	Universal gas constant (8.31439)	$J\ K^{-1}\ mol^{-1}$
r_a	Rehydration ability	kg water $(kg\ d.m.)^{-1}$
S_{yx}	Standard deviation of the estimation	kg water $(kg\ d.m.)^{-1}$
S_y	Standard deviation of the sample	kg water $(kg\ d.m.)^{-1}$
t	Time	s
T	Absolute temperature	K
VAR	Percentage of explained variance	%
W	Moisture content at time t	kg water $(kg\ d.m.)^{-1}$
W_e	Equilibrium moisture content	kg water $(kg\ d.m.)^{-1}$
x	Position	m
Subscripts		
calc	Calculated	
exp	Experimental	
l	local	
0	Initial value	

LITERATURE

Achanta, S., Okos, M.R. (1996), Predicting the quality of dehydrated foods and biopolymers. Research needs and opportunities. Drying Technology, 14(6), 1329-1368

Alves-Filho, O. 1984. Thin-layer drying and rewetting models to predict moisture diffusion in spherical agricultural products. Proceedings of the International Drying Symposium, Kyoto, Japan

Crank, J., 1975, The mathematics of diffusion, Clarendon Press, Oxford

Mulet, A. (1994), Drying modelling and water diffusivity in carrots and potatoes. Journal of Food Engineering, 22, 329-348

Sen, A., Srivastava, M., 1990, Regression analysis. Theory, methods and applications, Springer-Verlag New York Inc., New York

Simal, S., Mulet, A., Tarrazó, J., Rosselló, C. (1996), Drying models for green peas. Food Chemistry, 55(2), 121-128

Vázquez, G., Chenlo, F., Moreira, R., Costoyas, A. (2000), Effects of various treatments on the drying kinetics of *Muscatel* grapes. Drying Technology, 18(9), 2131-2144