

## Model for internal porosity development of different shaped foods

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### ABSTRACT

Three particular geometrical shapes of foods were prepared from food materials. Cuboidal (aspect ratio = 1:1, 2:1, 3:1), cylindrical (length: diameter = 1:1, 2:1, 3:1) and spheres were selected from potato, beans and peas respectively. Internal porosity was determined from solid density (theoretical) and particle density (experimental) during fluidised bed drying at different moisture contents. Solid density was calculated using formulae (conservation of mass and volume) already published in the literature by previous researchers. Determined porosity values were correlated with moisture ratio for different geometrical shapes.

**Keywords:** Porosity, shapes, solid density, particle density, model

### INTRODUCTION

Drying of foods is a major operation in the industry consuming larger amounts of energy. Drying operation is used as a primary operation for preservation of food materials or as secondary process in some manufacturing operations. This is a complex process involving mass and heat transfer accompanied by physical and structural changes (Senadeera 2009). The quality of food materials that undergo drying depends on their initial quality and changes during drying. Shape and size changes occur influencing their physical properties which will change their internal porosity, final texture and transport properties (Senadeera *et al.* 1998).

Porosity is the amount of air space or void in the material. The measure of porosity can be calculated from values of theoretical and practical data of particle density. As shrinkage affects porosity of food, Lewicki *et al.* (2004) proved that temperature and airflow from drying change the degree of damage of the internal plant tissue structure. This results in alteration of physical and mechanical properties of the food that leads to changing the amount of porosity.

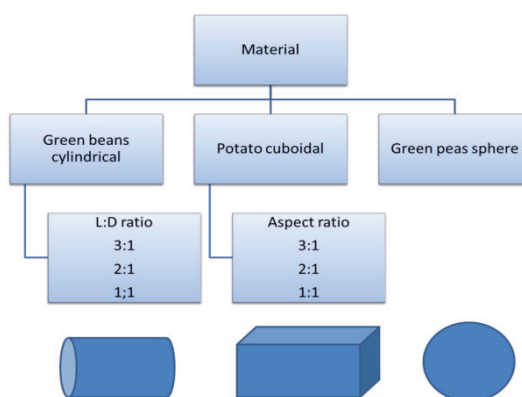
It can be argued that chemical composition of food also has an effect to the overall porosity (Karathanos *et al.* 1998). Chemical composition of food can be used in

calculating solid density from its constituents with a correction for drying temperature, experiments can be used for determining particle density. These two densities are then use to calculate the porosity inside the food.

The objective of this research is to understand the relationship between the development of internal porosity and the shape of the food particulates during fluidised bed drying. Also, a generalised model was derived for the porosity development with changes in moisture content during drying. This model equation was capable of describing the relationship between porosity and moisture ratio of all shapes under consideration.

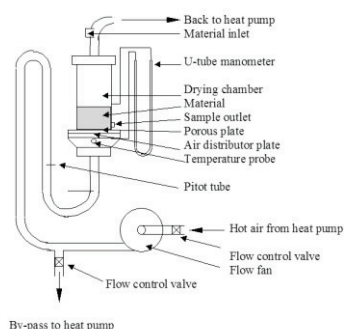
### MATERIALS AND METHODS

*Raw Materials and material preparation:* Three vegetables was selected and different food shapes were prepared—they were potato, peas and green beans with cuboidal, spherical and cylindrical shapes respectively as shown in Figure 1. The objective of this experiment is to investigate porosity changes of these three different shaped foods during fluidised drying at three different temperatures, 30, 40 and 50 °C.



**Fig. 1. Materials and shapes**

Experimental design for drying experimentation: Three batches were prepared at once and used for three drying temperatures. Two replicate batches were prepared for cut beans (3 L:D ratios) and diced potato (3 aspect ratios). Three replicate batches were prepared for peas.



**Fig. 2. Schematic of the drying loop**

**Analysis of experimental data and modeling:** Solid particle density was calculated for different moisture contents similar to experimental moisture contents using Equation 1. Porosity was calculated using equation 2 and temperature effects were introduced to solid density at different drying temperatures.

$$\rho_a = a + B MR + c \exp(-d MR) \tag{1}$$

where,

$\rho_a$  – particle density, MR- moisture ratio

For calculation of solid density food materials was considered as multi-phase systems. When the mixing process conserves mass and volume principle, then density of the multiphase system can be written as in equation 2. Solid particle density based on each composition is calculated by this equation:

$$\frac{1}{\rho_s} = \sum_{i=1}^n \frac{w_i}{\rho_i} \tag{2}$$

Where,

$\rho_s$  – solid density,  $w_i$  – percentage by weight and  $\rho_i$  – composition solid density.

Main compositions considered for the materials under consideration are water, protein, carbohydrates, fat and ash. Their raw (initial) compositions are given in the Table 1.

**Table 1 Initial composition of the materials**

Material	Water (%)	Protein (%)	Fat (%)	Carbohydrate (%)	Ash (%)
Potato	81.7	1.7	0.3	16.1	0.2
Beans	90.7	1.9	0.5	3.2	3.7
Peas	74.6	6.9	1.5	11.3	5.7

Source: Food Properties Hand Book (2007), Rahman M S (Ed)

Through curve fitting and optimisation, a generalised governing equation was created. Coefficient of determination was used to find the suitability of the models.

### RESULTS AND DISCUSSION

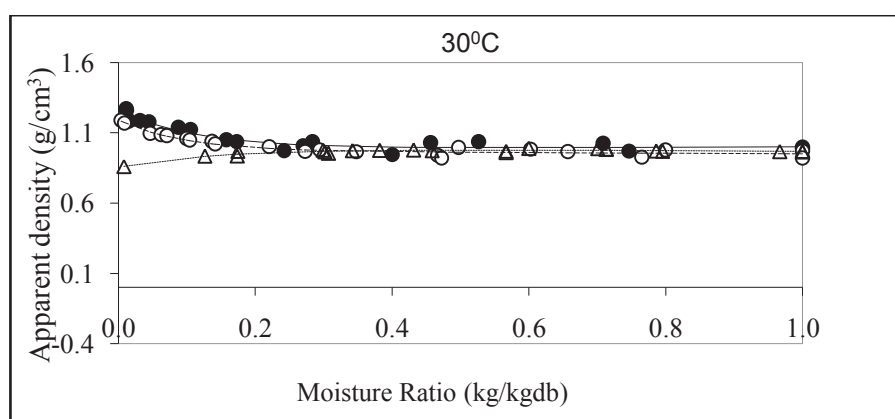
**Particle density (apparent):** Experimental values of particle density were fitted to a non-linear model similar to Lozano *et al.* (1994) as these finding was published earlier (Senadeera 2009) was not shown here. But individual apparent particle density values were used for porosity determination. (Figure 3 for beans)

**Porosity determination and model formulation:** Internal porosity was calculated by using solid density (theoretical) and particle density (experimental)

$$\epsilon = 1 - \frac{\rho_a}{\rho_s} \tag{3}$$

where,

$\epsilon$  – porosity,  $\rho_s$  – solid density and  $\rho_a$  – apparent particle density



**Fig. 3. Particle density variations of beans during fluidised bed drying**

(• experimental L:D =1:1 - model L:D =1:1); (o experimental L:D=2:1 -- model L:D=2:1); (Δ experimental L:D =3:1 ... model L:D =3:1)

A three parameter exponential decay curve added to a linear term with a fractional exponent was chosen. A generalised governing equation was created (equation 4).

$$\epsilon = a \cdot e^{-b \cdot (MR)^n} + c \cdot (MR)^m \tag{4}$$

where,

$\epsilon$  = porosity, MR = moisture ratio and a, b, n, c and m are model parameters.

Figure 5 shows potato (cuboidal) porosity variation for aspect ratios of 3:1, 2:1 and 1:1 at 50 °C drying temperature and model graphs. Similar charts was for other materials and not shown. The model parameters of, equation 4 is shown in the Table 2 below.

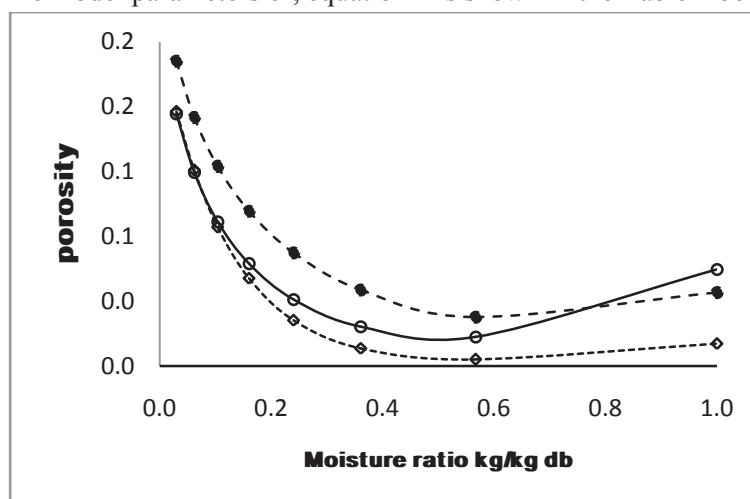


Fig. 5. Potato porosity variations at 50° C  
Aspect ratio  $\diamond$  1:1  $\circ$  2:1  $\bullet$  3

Table2. Porosity model parameters

Material	Temp	size	a	b	n	c	m	R <sup>2</sup>
Potato	30	1	0.2034	6.4767	0.9574	0.0244	3.3	0.9997
		2	0.3231	5.4856	0.8182	0.0259	3.3	0.9999
		3	0.3135	4.8124	0.6744	0.0151	3.3	0.9990
	40	1	0.2157	7.8815	0.8864	0.0444	3.3	0.9984
		2	0.2356	4.6205	0.9010	0.000	3.3	0.9999
		3	0.2678	5.5097	0.7957	0.0042	3.3	0.9981
	50	1	0.2002	8.2192	1.0024	0.0137	3.3	0.9991
		2	0.2278	4.8689	0.7264	0.0578	3.3	0.9985
		3	0.2586	3.4713	0.6812	0.0373	3.3	0.9982
Beans	30	1	0.1715	1.4905	0.4895	0.0000	1.7	0.9638
		2	0.6904	2.1267	0.1346	0.0000	1.7	0.9978
		3	0.5312	3.1946	0.6125	0.0426	1.7	0.9997
	40	1	0.1418	12.9664	3.6451	0.0326	1.7	0.8345
		2	0.1858	6.5309	7.5219	0.0939	1.7	0.9844
		3	0.9104	3.0917	0.4126	0.0157	1.7	0.9989
	50	1	0.5048	2.7382	0.4391	0.0437	1.7	0.9996
		2	0.3103	2.0628	0.6765	0.0508	1.7	0.9993
		3	1.9951	4.0616	0.2406	0.0785	1.7	0.9988
Peas	30		0.1289	4.9600	1.2617	0.0748	1.2	0.9998
	40		0.1228	4.3131	1.6155	0.0762	1.2	0.9895
	50		0.2380	2.6751	0.8247	0.0607	1.2	0.9998

## CONCLUSIONS

Internal porosity development behavior of the different food particulates change as the drying proceeded. It is important to understand the changes in porosity, so that predictions can be made related to food structure. Further experiments are necessary to investigate the relation between this approach and actual porosity development.

### Nomenclature

a, b, c, d	constants
D	diameter (m)
L	sample length (m)
m	moisture content (kg/kg)
MR	moisture ratio
m, n	model exponents
T	temperature (K)
$\epsilon$	internal porosity
$\rho$	particle density ( $\text{g/cm}^3$ )
Subscripts	
i	integer
a	apparent
s	solid

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