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DRYING CONSTANT AND SHRINKAGE CONSTANT RELATIONS OF DIFFERENT SHAPED FOOD PARTICULATES: EMPIRICAL MODELS

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Abstract: Experiments were undertaken to study relationship between drying constant and shrinkage constant of different shaped food particulates during fluidised bed drying. Three particular geometrical shapes of parallelepiped, cylindrical and spheres were selected from potatoes (aspect ratio = 1:1, 2:1, 3:1), cut beans (length: diameter = 1:1, 2:1, 3:1) and peas respectively. Volumetric shrinkage coefficient was compared with drying constant for all materials at these three temperatures to understand the effects of drying constant on shrinkage constant for each material under investigated drying conditions. Simple mathematical models were obtained for volumetric shrinkage constant and drying constant relation.

Keywords: shrinkage, drying constant, fluid bed drying, aspect ratio, length diameter ratio

INTRODUCTION

Drying of foods is a major operation in the food industry, consuming large quantities of energy. Dried foods are stable under ambient conditions, easy to handle, possess extended storage life and can be easily incorporated during food formulation and preparation. The drying operation is used either as a primary process for preservation, or a secondary process in certain product manufacturing operations. Drying is a complex process and involves simultaneous mass and heat transfer accompanied by physical and structural changes (Fusco et al., 1991). Shape and size of the products change appreciably, influencing their physical properties, which in turn modify final texture and transport properties of the dry foods (Karel, 1991).

Shrinkage is important to consider as it influences several other physical properties, such as bulk density and particle shape and density, and can also cause internal stresses. Shrinkage also influences moisture removal rate during the drying process (Balaban, 1989; Suarez and Viollaz, 1991; Khraisheh et al., 1997).

The objective of this study is, to understand volume changes of different shaped food particulates during fluid bed drying and relate this change to drying constant by suitable models.

MATERIAL PREPARATION

Green beans

Fresh green beans Phaseolus vulgaris of the variety Labrador was used for producing cylindrical particles (diameter 10±1 mm). Both ends of the beans were removed and only the middle portions, which resemble a cylindrical shape, were used to produce three length to diameter ratios of 1:1, 2:1 and 3:1.

Potato

Potato Solanum tuberosum of the variety Sebago was washed and brushed to remove skin and mud. Washed potato was pushed through a stainless steel square cutter to make parallelepipeds with aspect ratio of 3:1, 2:1 and 1:1, the particles were cut carefully to lengths of 19.5, 13 and 6.5 mm respectively.

Green peas

Fresh green peas Pisum sativum of the variety Bounty were shelled by hand and graded using a wire mesh and those with average diameter 10±1 mm were selected. All samples were stored in a cold room for 24 hours at 4°C before experimentation to equilibrate moisture content.

Drying in a fluidised bed

Fluidised bed dryer was connected to the heat pump dehumidifier system (Figure 1). The drying conditions of 30°C, 40°C and 50°C, were set by the temperature controller in the heat pump dehumidifier system, and the drying set up was run for 2 hours to achieve steady state conditions of drying before material introduction. The relative humidity of drying was 15%. Initial bed height of 150 mm was used and
hot air velocity passing through the material bed was kept at a constant value of 2.2 m/s to keep within the limit of fluidisation and terminal velocity of all materials. The air-flow entering the dryer was controlled by flow control valves. Samples were collected from the dryer at 30 minutes intervals through the sample outlet.

Change in volume ratio (VR) with moisture ratio (MR) is shown in Figure 2 for L:D = 1 at 30°C. Similar shrinkage behaviour was observed for all the other L:D ratios and temperatures. It was observed sudden decrease in shrinkage between MR = 1 and MR = 0.8 for all L:D ratios. After MR = 0.8, the shrinkage followed an exponential curve for all L:D ratios at drying temperatures of 30°C, 40°C and 50°C which is considered as the region for the model.

**Volume Measurement**

The volume of the particles was measured by the liquid displacement method using liquid paraffin (SG = 0.8787 at 30°C) as the medium, using a measuring cylinder of 22 mm inside diameter and 50 ml capacity (Zogza et al., 1994).

**Moisture content**

The vacuum oven was used to measure the moisture content of the particles according to AOAC method 934.06 (1995) (Rosello et al., 1997).

**Analysis of experimental data**

The data were analysed for the analysis of variance (ANOVA) to evaluate differences, and, linear regression and non-linear regression to obtain suitable models. For all the analysis the Statistical Analysis System software (SAS, 1985) was used. Model validity was tested using measures of coefficient of regression ($R^2$) and Mean Absolute Error Percentage (MAE%).

**RESULTS AND DISCUSSION**

**Shrinkage behaviour**

The shrinkage behavior (change in volume ratio) of the beans with moisture ratio for different L:D ratios at different drying temperatures were correlated to the Equation 1 and for potato and peas equation 2 respectively. (Table 1)

$$VR = 1 - B e^{-KMR} \quad (MR < 0.8) \quad (1)$$

$$VR = A + B MR \quad (2)$$

Where, $VR =$ volume ratio, $A$, $B$, $K =$ constants, $MR =$ moisture ratio

Unlike the case of beans, shrinkage was linear in potato and peas reported by many researchers (Ratti, 1991; McMinn and Magee, 1997; Wang and Brennan, 1995)

**Drying Kinetics**

Drying occurred only in the falling rate period for all materials during this investigation. The average moisture content was expressed as non-dimensional moisture ratio 'mr' (Equation 3) and simple model (Eq.4) used to model the drying curves with time (h).

$$mr = (m - m_f)/(m_0 - m_f) \quad (3)$$

$$mr = \exp (-kt) \quad (4)$$
Where, \( m \) = moisture at given time (kg/kg db), \( m_o \) = initial moisture (kg/kg db) and \( m_e \) = equilibrium moisture content (kg/kg db), \( k \) = drying constant.

The estimated drying constants are given within brackets in Table 1.

Table 1: Calculated shrinkage constants and drying constants

<table>
<thead>
<tr>
<th>Material</th>
<th>30°C</th>
<th>40°C</th>
<th>50°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bean L:D = 1:1</td>
<td>1.40(0.4005)</td>
<td>1.31(0.5679)</td>
<td>1.03 (0.8770)</td>
</tr>
<tr>
<td>Bean L:D = 2:1</td>
<td>1.45(0.2361)</td>
<td>1.37(0.3798)</td>
<td>1.27 (0.6016)</td>
</tr>
<tr>
<td>Bean L:D = 3:1</td>
<td>1.71(0.1170)</td>
<td>1.40(0.2428)</td>
<td>1.33 (0.4497)</td>
</tr>
<tr>
<td>Potato AR = 1:1</td>
<td>0.890(0.7274)</td>
<td>0.880(0.8692)</td>
<td>0.871 (1.206)</td>
</tr>
<tr>
<td>Potato AR = 2:1</td>
<td>0.887(0.6295)</td>
<td>0.874(0.7126)</td>
<td>0.907 (0.8750)</td>
</tr>
<tr>
<td>Potato AR = 3:1</td>
<td>0.906(0.5933)</td>
<td>0.861(0.6428)</td>
<td>0.862 (0.8518)</td>
</tr>
<tr>
<td>Peas</td>
<td>0.7961(0.1867)</td>
<td>0.7785(0.3001)</td>
<td>0.748 (0.5342)</td>
</tr>
</tbody>
</table>

Effect of drying rate on shrinkage rate

Figure 3, shows the variation of the shrinkage rate (\( K \) in equation 1 for beans) with the drying rate \( k \) (Equation 4) for beans. Shrinkage constant for beans increased with decreased drying constant (lower rate of drying results in the higher shrinkage). Similar behaviour was also found for the peas. But for the potato shrinkage constant changed in a very narrow range compared to the drying constant and could not be modeled to an equation. Model equations showing relation between drying constant and shrinkage are given Table 2.

CONCLUSIONS

It was observed that there is a relation between volume reduction and drying constant during drying. Potato drying constant change is in a very narrow margin with drying constant. Simple mathematical models can be derived for beans and peas showing their relation of shrinkage constant and drying constant. These models could be further improved by incorporating structural changes during drying.

Table 2 Model equations for drying constant and shrinkage constant

<table>
<thead>
<tr>
<th>Material</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bean L:D = 1:1</td>
<td>( K = -0.7819 k + 1.7334 )</td>
</tr>
<tr>
<td>Bean L:D = 2:1</td>
<td>( K = -0.5574 k + 1.6064 )</td>
</tr>
<tr>
<td>Bean L:D = 3:1</td>
<td>( K = -1.0748 k + 1.7741 )</td>
</tr>
<tr>
<td>Peas</td>
<td>( K = -0.136 k + 0.8206 )</td>
</tr>
</tbody>
</table>

NOMENCLATURE

\( A, B \) constants
\( k \) drying constant
\( K \) constant
\( L \) length \( \text{m} \)
\( D \) diameter \( \text{m} \)
\( m \) moisture \( \text{kg/kg db} \)
\( mr \) dimensionless moisture
\( t \) time \( \text{h} \)

Subscripts
\( o \) initial
\( e \) equilibrium

REFERENCES


