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Experimental study on shrinkage and rehydration of seed during drying process

Cai Liang Shi Mingheng

(Department of Power Engineering, Southeast University, Nanjing 210096, China)

Abstract: Biomaterial will shrink during the drying process. The characteristics of shrinkage and rehydration of fresh peas were studied. Drying curves, shrinkage and rehydration curves of peas without seed coats and whole peas were compared. In addition, different volumetric shrinkage coefficients were obtained and discussed. The results show that seed coats resist moisture movement not only from inside to outside but also from outside to inside during different drying conditions. During a seed's drying process, the drying curve is similar to the shrinkage curve. The higher the heat flux is, the less drying time is needed, and in the meantime, volume would shrink more and more intensively. Dried media will break easily at high heat flux. When we create a drying regime, both drying speed and the quality of dried media should be considered.

Key words: drying process; shrinkage characteristics; rehydration characteristics

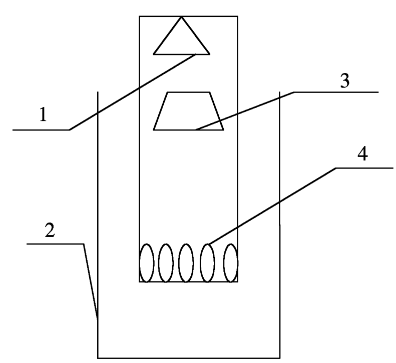
In recent years, much more attention[1-3] is paid to the quality of foods during drying process. With water evaporation, material physical structure is changed. Shrinkage takes place with the change of humidity and temperature during the drying process. Stress will result, even causing biomaterial to break. So shrinkage characteristics should be considered in a drying model.

Vegetables should be dried to low moisture content for storing if their moisture is high. Before eaten, dehydrated vegetables should be rehydrated. Whether they return the initial volume or not, it is very important for the dehydrated vegetables.

Seed coat resists the movement of moisture content not only from inside to outside but also from outside to inside under different conditions. It also changes shrinkage and rehydration characteristics of material. In this study, a volumetric shrinkage coefficient has been introduced. Drying curves, shrinkage and rehydration curves of the pea without seed coat and whole pea, are obtained experimentally. Volumetric shrinkage coefficients at different drying conditions are compared and discussed.

1 Experimental Apparatus and Methods

An experimental drier system is shown in Fig.1. It is composed of an electronic balance, an insulation material, an infrared bulb and drying media. Power can be changed by booster. Mass of media can be measured by an electronic balance. Its absolute error is 0.01 g.



1— Electronic balance; 2—Insulation material; 3—Infrared bulb; 4— Media

Fig.1 Schematic diagram of the thin layer drier

Constant temperature zone is used in the rehydration experiment. The temperature of water is 40 ℃. The measuring uncertainty is about 1 ℃.

Experimental material is fresh peas. Ratio rehydration was defined in Ref.[4].

$$R_f = \frac{m_f}{m_g} \tag{1}$$

where m_g and m_f are the mass of the material before and after rehydration.

The device[5] for measuring granular material's volume is shown in Fig.2. It consists of two different volumes tanks, the reference tank is slightly bigger than the sample tank. A U-tube manometer is used to measure air pressure, its absolute error is 4.9 Pa. At the beginning the material is in the sample tank,

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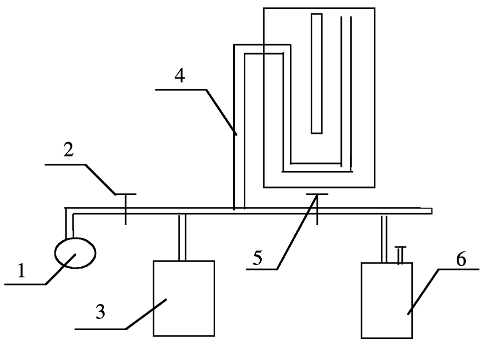
Biographies: Cai Liang (1973—), male, doctor; Shi Mingheng (corresponding author), male, professor, mhshi@seu.edu.cn.



1—Pump; 2—Control valve 1; 3—Reference tank;
4—U-tube; 5—Control valve 2; 6—Sample tank

Fig.2 Volume measurement device for granular material

control valve 2 is closed and air is supplied to the reference tank. When the expected reference tank pressure is reached, control valve 1 is closed and the pressure in reference tank is allowed to reach. After stabilization, the stabilized pressure, defined as P_1, can be obtained. Then control valve 2 is opened to allow the air pressure in the system to reach equilibrium. At this moment, the pressure and temperature in the system remain P_2 and T_2. The sample volume can be calculated by using the ideal gas equation as

$$\frac{P_1 V_1}{T_0} + \frac{P_0(V_2 - V_s)}{T_0} = \frac{P_2(V'_1 + V_2 - V_s)}{T_2} \quad (2)$$

where V_1 is the initial volume of the reference tank and connecting tube (m^3); V'_1 is the volume of the reference tank and connecting tube, as control valve 2 is opened, V_1 changes to V'_1(m^3); V_2 is the volume of the sample tank and the connecting tube (m^3); V_s is the volume of the sample (m^3); P_0 is the initial air pressure (Pa); T_0 is the initial air temperature (K).

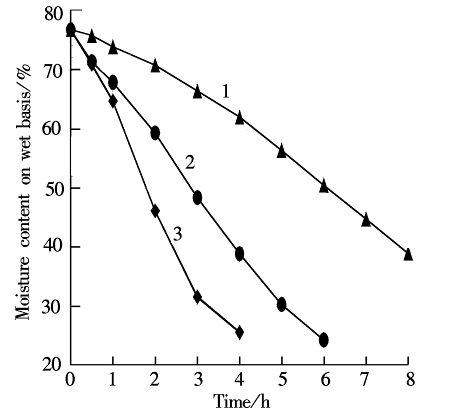
Because we have $T_0 = T_2$, the sample volume can be calculated by the following formulation:

$$V_s = V_2 - \frac{P_1 V_1 - P_2 V'_1}{P_2 - P_0} \quad (3)$$

2 Results and Discussion

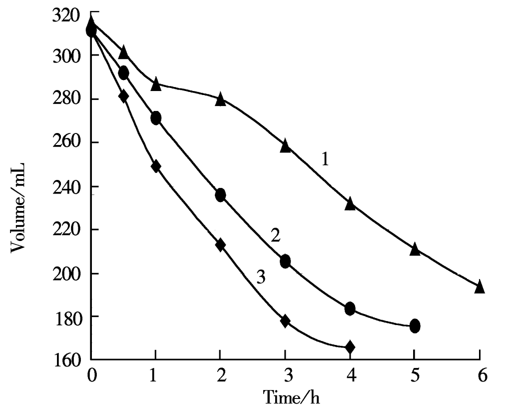
2.1 Drying curve and shrinkage curve

From Fig.3, it is shown that for higher heat flux, little drying time is needed. Fig.4 is a shrinkage curve. It looks similar to the drying curve. The higher drying heat flux is, the more shrinkage should occur. Stress will be induced, and material may be broken. The choice of an optimum drying flux, not only drying speed, but also the quality of drying media, especially for biomaterial and food materials, should be considered.



1—Heat flux is 586 W/m^2; 2—Heat flux is 1 381 W/m^2;
3—Heat flux is 2 139 W/m^2

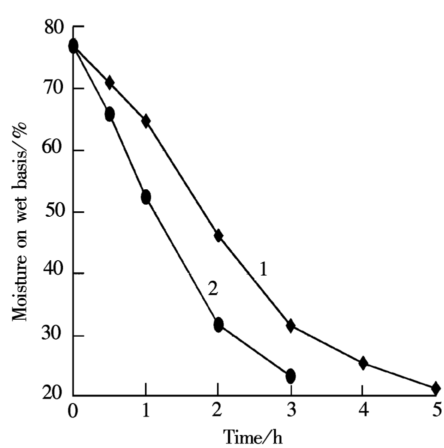
Fig.3 Drying curve for whole peas



1—Heat flux is 586 W/m^2; 2—Heat flux is 1 381 W/m^2;
3—Heat flux is 2 139 W/m^2

Fig.4 Shrinkage curve for whole peas

Fig.5 shows that seed coat resists moisture content moving from inside to outside. Fig.6 shows that seed coat also decreases shrinkage during the drying process. Thus the seed coat has a protective function for material to broken. Compared with the seeds without coat, the coat can also prevent too much moisture loss during the drying process.



1—Whole peas; 2—Peas without skin

Fig.5 Drying curve (heat flux is 2 139 W/m^2)

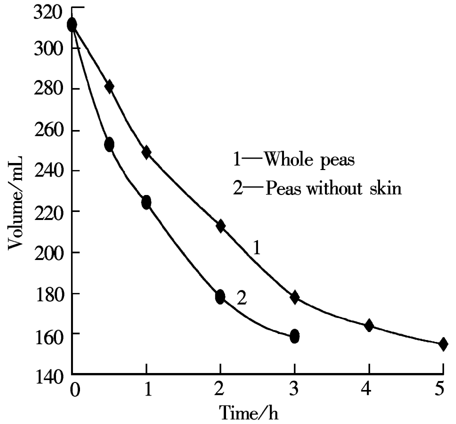


Fig.6 Shrinkage curve (Heat flux is 2 139 W/m^2)

2.2 Volumetric shrinkage coefficient

Analogous with the coefficient of thermal expansion[6], a coefficient of volumetric hygroscopic shrinkage is defined as

$$\beta_V = \frac{dV}{V} \cdot \frac{1}{dM} \quad (4)$$

where β_V is the volumetric shrinkage coefficient; V is the material's volume; M is the moisture content on a wet basis. Assuming that the coefficient β_V is a constant throughout the dehydration process, Eq. (4) can be integrated as

$$\beta_V \int_{M_0}^{M} dM = \int_{V_0}^{V} \frac{1}{V} dV \quad (5)$$

where M_0 is the initial moisture content and V_0 is the initial volume. Integrating Eq. (5) and re-arranging the resulting relationship yield:

$$\beta_V (M - M_0) = \ln\left(\frac{V}{V_0}\right) \quad (6)$$

$$V = V_0 e^{-\beta_V (M_0 - M)} \quad (7)$$

Eq. (6) can be fitted by the experimental data for each drying condition using the least squares method[6].

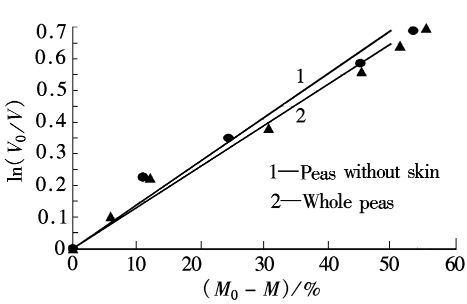


Fig.7 Volumetric shrinkage coefficient (heat flux is 2 139 W/m^2)

Fig.7 shows that the volumetric shrinkage coefficient for peas without skin is larger than that for whole peas. It means that the coat has a protective function to keep seed in its original manner.

2.3 Ratio of rehydration

Fig.8 shows that the ratio of rehydration for peas without skin is larger than that for whole peas. It means that when drying materials are in wet conditions, seed coat can also resist moisture movement from outside to inside.

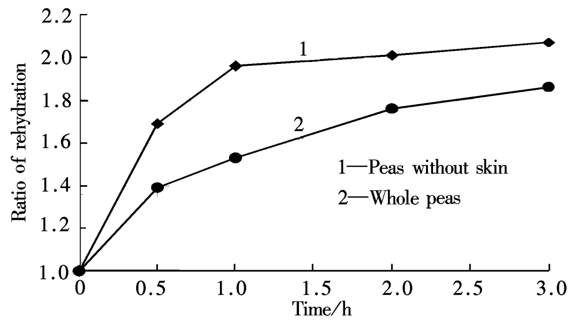


Fig.8 Ratio of rehydration (heat flux is 2 139 W/m^2)

3 Conclusions

1) During a seed's drying process, the drying curve is similar to shrinkage curve. The higher the heat flux is, the less drying time is needed. At the same time, volume shrinks more and more intensively. Dried media will break easily at high heat flux. When we create a drying regime, both drying speed and the quality of dried media should be considered.

2) Seed coat not only resists moisture movement from inside to outside under dry conditions, but also resists moisture movement from outside to inside under wet conditions. As setting up a drying model, we should consider the seed coat's protective function.

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种子干燥过程中收缩特性和复水特性的试验研究

蔡 亮　　施明恒

(东南大学动力工程系, 南京 210096)

摘　要　生物材料干燥过程中会发生收缩现象.本文对新鲜豌豆的收缩特性和复水特性进行了研究.比较了种皮对干燥曲线、收缩曲线、复水曲线和体积收缩系数的影响.研究表明,种皮不仅阻碍湿分由内向外运动也阻碍湿分由外向内运动.种子干燥过程中,干燥曲线与收缩曲线形状相似.热流密度越大,干燥速度越快,种子收缩也越快,同时种子也越容易破裂.在制作干燥方案时,考虑干燥速度的同时必须考虑种子的质量.

关键词　干燥过程; 收缩特性; 复水特性

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