УДК 66.047

DRYING CHARACTERISTICS OF GREEN PEAS IN FLUIDIZED BEDS

Zhanyong Li[1], Jingsheng Ye[1], Hongtai Wang[2], Ruifang Wang[1]

College of Mechanical Engineering, Tianjin University of Science and Technology, Tianjin, P. R. China (1);
School of Material Science & Chemical Engineering, , Tianjin University of Science and Technology, Tianjin, P. R. China (2)

Represented by a Member of the Editorial Board Professor T. Kudra

Key words and phrases: dispersion of solids; fluidizing air; pulsating air stream.

Abstract: A modified fluidized bed, termed the pulsed fluidized bed (**PFB**), was developed to eliminate some limitations of the conventional fluidized bed by superposing a pulsating air stream on the continuously flowing fluidizing air. Drying of green peas was carried out to assess the advantages of such a pulsed fluid bed over the conventional fluid bed. Due to good dispersion of solids by the pulsing air flow, a higher drying rate is realized in PFB with lesser color degradation. The solids shrinkage and sorption isotherms are also presented.

Nomenclature

a^* – CIE-Lab value (green-red);
b^* – CIE-Lab value (blue-yellow);
d_p – particle diameter, mm;
H – static bed height, mm;
I – intermittency, $I = t_{on}/(t_{on}+t_{off})$;
L^* – CIE-Lab value (brightness);
m – material throughput, kg;
R_d – drying rate;
T – drying temperature, K;
T_{exit} – gas outlet temperature, K;
t – time, s;
t_{off} – off-period, s;
t_{on} – on-period, s;
u – average superficial gas velocity in one pulsing cycle, m/s;
u_{mf} – minimum fluidization gas velocity, m/s;
w – mass of water adsorbed per unit dry green pea, kg/kg;
X – moisture content, kg water/kg dry matter;
ΔE – total color difference,

$$\Delta E = \sqrt{\left(L^* - L_o^*\right)^2 + \left(a^* - a_o^*\right)^2 + \left(b^* - b_o^*\right)^2}\ ;$$

ρ_p – particle density, kg/m^3.

Introduction

Fluidization is widely used when processing solid particles in such technologies as drying, combustion, synthesis, etc. Generally, fluidized bed dryers are considered superior to other conventional dryers when processing non sticky and narrow size-distributed particles with maen size ranging from 50 μm to 2 mm. In order to extend its applications, some modified fluidized bed dryers have been developed, e.g., spouted bed, vibrated fluidized bed, and pulsed fluidized bed (**PFB**), among which the pulsed fluidized beds have been reported to have better fluidization quality, effective gas-solid contact, enhancement in heat and mass transfer and the like [1 – 7].

In the literature, various ways of pulsating the fluidizing gas are described [1, 6, 8 – 10]. It is noted that only the pulsing flow is not appropriate to fluidize the bed of large particles, as it may be cumbersome to the pulsating device. Therefore, we proposed to use a combined gas stream to fluidize the large particles, viz. a continuous gas flow plus a pulsing gas flow [11]. Such a combination of the constant and pulsed gas streams was claimed to facilitate pulse fluidization in another design of a pulsed fluid bed dryer [12]. The objective of this paper is thus to investigate the characteristics of such a pulsed fluidized bed for processing large particles. Evaluation of the drying rate was made for such a PFB and the conventional fluid bed (**FB**) using green peas as the representative material. Furthermore, the color degradation was investigated for the rehydrated products.

Experimental

Fig. 1 shows the schematic of the experimental apparatus. A drying chamber, made of acrylic resin, has an inside diameter of 180 mm and a cylinder height of 500 mm. The gas distributor was made of a steel plate with about 10 % of open area and 2 mm drilled holes. A steel plate with large drilled holes of 10 mm in diameter was set 200 mm below the gas distributor to pre-distribute the fluidizing gas. Two Ring-type blowers were used to supply independently a constant air flow and a pulsation flow. The pulsing air stream was controlled by electromagnetic valves. A pulsing cycle was 1.0 s/1.0 s (0.5 Hz) as a primary test. The fluidization gas in the range of 120 – 320 m^3/h was heated to the desirable temperature (80…90 °C) in an electric heater with a PID controller.

Frozen green peas after blanching were used in the experiments. Prior to drying, the peas (d_p = 9.3 mm and ρ_p = 1040 kg/m^3 in average) were thawed out and wiped off the free surface water.

The weight loss of green peas during drying versus drying time was determined by monitoring the absolute humidity difference between the inlet gas and exhaust gas (Hygromer HP 100 A). The dry matter of green pea was determined after 6 hours of drying at 100 °C in a vacuum oven at < 3.3 kPa. The temperatures along the bed were measured with K-type thermocouples. All the analog signals were acquired by a data acquisition system (HP Benchlink Data Logger), connected to a PC for acquiring and storing digital data. The color changes of green peas due to drying were measured with a spectrophotometer.

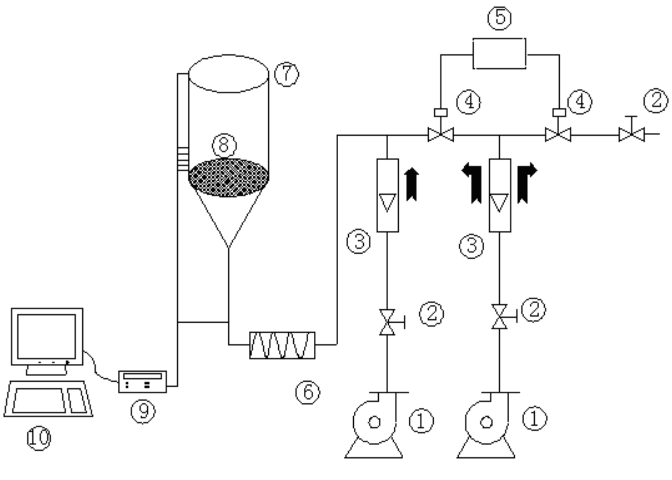

Fig. 1 Schematic of experimental apparatus:
1 – blower; *2* – regulating valve; *3* – flow meter; *4* – electromagnetic valve; *5* – controller; *6* – heater; *7* – drying chamber; *8* – gas distributor; *9* – data logger; *10* – PC

Results and discussion

Sorption isotherms for green peas

Vacuum dried green peas were pulverized and further degassed in an automatic vapor adsorption apparatus, Belsorp for sorption experiments. The results at 30 °C are shown in Fig. 2. The isotherms exhibit hysteresis below air relative humidity of 80 %. Even at low relative humidity, the samples could not reach much lower moisture content.

Determination of minimum fluidization velocity

For fluidized beds, the solids size has an effect on the minimum fluidization gas velocity and then on the operating gas velocity. Firstly, thin-layer drying of green peas in a drying oven was performed. At a time interval of 5 – 30 min, peas were sampled for determination of moisture content and solid size. Fig. 3 shows the drying curves as a function of drying temperature (each set of data was regressed with exponential function). Obviously, higher temperature enhances the drying rate, as can be seen that lower moisture content at the same drying time.

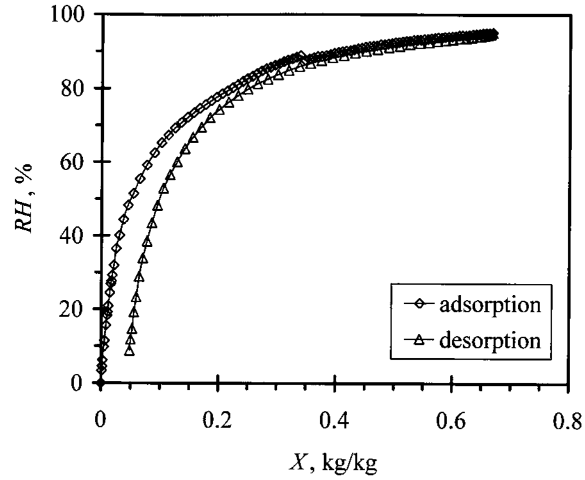

Fig. 2 Sorption isotherms for green peas at 30 °C

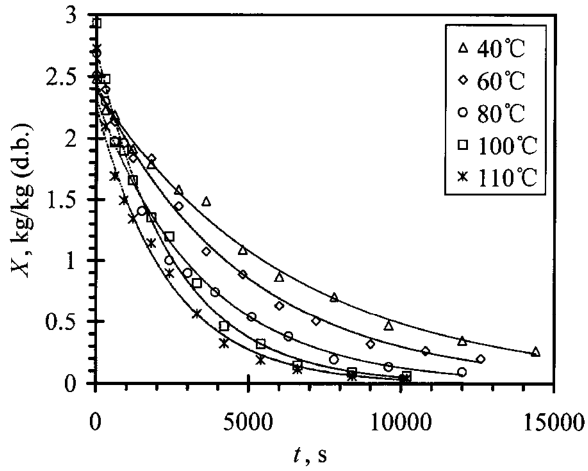

Fig. 3 Thin-layer drying curves of green peas

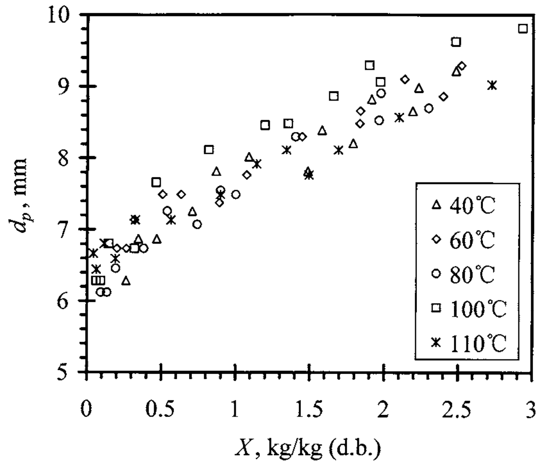

Fig. 4 Changes of average particle diameter with moisture content

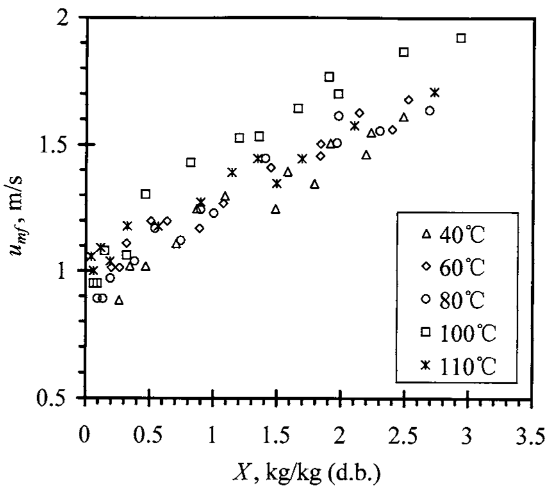

Fig. 5 Changes of minimum fluidization velocity with moisture content

Generally, the size of peas decreases linearly with the moisture content, as seen in Fig. 4. The effect of drying temperature on the solids shrinkage is not clear in the present study.

With the information on solids size and density (ρ_p = 1040 kg/m^3), we can use the equation of Wen and Yu [13] to calculate the minimum fluidization velocity, the results of which are presented in Fig. 5. Approximately, the minimum fluidization velocity changes linearly with the moisture content. In the operation of fluidized bed, it is advisable to change the operating gas velocity for energy saving.

Comparison of drying kinetics in PFB and FB

Fig. 6 shows the drying kinetics of green peas in the PFB and FB at T = 80 °C and H ≈ 50 mm. The moisture migration is controlled by diffusion in the kernel, so no constant rate period exists. It can be seen that pulsing operation is effective for promotion of a drying rate. In the PFB, green peas might be exposed to the lower gas temperature due to uniform heat transfer in the course of a drying process, since the temperature of exhausted gas is lower than that in the FB. No significant difference in the shape of dried green peas was observed between the PFB and FB.

To evaluate the product quality, the green peas after drying for 100 min were rehydrated in distilled water at 25 °C. The water uptake (w) is discernibly higher for the green peas dried in PFB (Fig. 7) and likely results from weaker case-hardening. Texture measurements, unfortunately not performed in this study, should help in making the conclusive statement. The color data of rehydrated green peas are presented in Table 1. It can be said that greenish tint of green peas is maintained better through drying in the PFB because of lower material temperature due to intermittent heat supply as well as higher water evaporation.

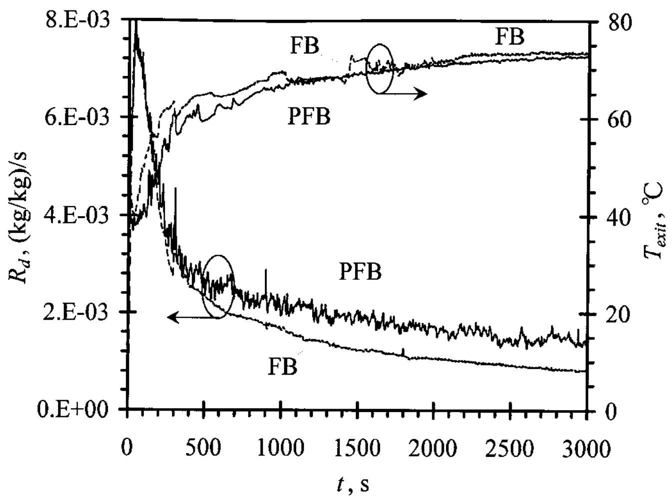

Fig. 6 Comparison of drying kinetics for green peas in pulsed fluidized bed and in conventional fluidized bed ($t_{on} = t_{off} = 1$ s, u =3.38 m/s, m = 1.0 kg, T = 80 °C)

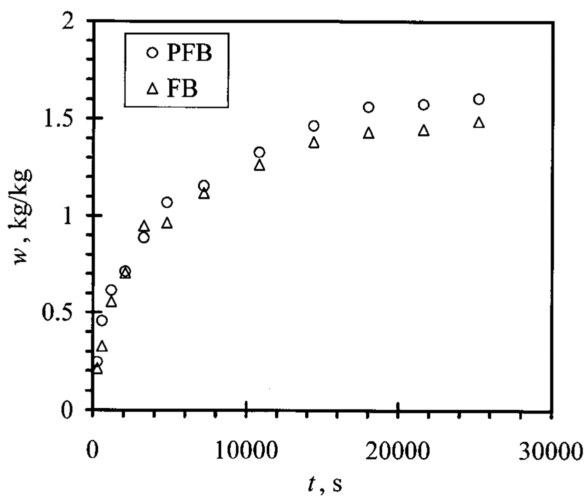

Fig. 7 Rehydration curves of green peas dried in pulsed fluidized bed and conventional fluidized bed

Table 1

Color properties of dried green peas

Material	Raw material	FB dried		PFB dried	
T,°C	30	80	90	80	90
L^*	53.2	54.1	51.8	53.0	51.8
a^*	–21.2	–14.4	–12.9	–15.4	–14.0
b^*	37.5	36.1	38.4	37.8	36.9
ΔE	–	7.24	9.3	5.96	8.82

Conclusions

The PFB drying of green peas is superior to that in FB in terms of drying rate and color preservation. The present drying technique will be suitable to other large particles especially for heat sensible materials such as agricultural products. Due to reduction in moisture content and/or shrinkage during the drying process, the pulsing flow can be regulated or cut-off at the final drying phase.

Acknowledgments

The research is sponsored by the University Scientific & Technological Development Foundation of Tianjin Municipal, China (Project No. 20041208) and Research Foundation of Tianjin University of Science & Technology (Project No. 20040109).

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Характеристики сушки зеленого гороха в псевдоожиженном слое

Жанйонг Ли[1], Джингшенг Джи[1], Хонгтай Уонг[2], Руифай Уонг[1]

Колледж механической инженерии,
Пекинский университет наук и технологии, Пекин, Китай (1);
Школа наук о материалах и химической инженерии,
Пекинский университет наук и технологии, Пекин, Китай (2)

Ключевые слова и фразы: распределение частиц; псевдоожижающий воздух; пульсирующий воздушный поток.

Аннотация: Разработан модифицированный псевдоожиженный слой, названный пульсирующим (**ППС**), чтобы устранить некоторые ограничения обычного псевдоожиженного слоя, путем наложения пульсирующего воздушного потока на непрерывно подаваемый псевдоожижающий воздух. Выполнены исследования сушки зеленого гороха, чтобы оценить преимущества такого слоя по сравнению с обычным. Благодаря хорошему распределению частиц пульсирующим воздушным потоком, в ППС реализуется более высокая скорость сушки при меньшей деградации цвета. Представлены также усадка частиц и изотермы сорбции.

Charakteristiken des Trocknens der grünen Erbse in der quasiflüssigen Schicht

Zusammenfassung: Es ist die modifizierte quasiflüssige Schicht entwickelt, um einige Beschränkungen der gewöhnlichen quasiflüssigen Schicht mittels des Auferlegens des pulsierend Luftstroms auf ununterbrochen gerichten quasiflüssigen Luft zu entfernen, erarbeitet. Es sind die Forschungen der Trocknung der grünen Erbse erfüllt, um die Vorteile solcher Schicht im Vergleich zu bewerten. Dank der guten Dispersion der Teilchen vom pulsierenden Luftstrom wird die höhere Geschwindigkeit der Trocknung bei kleinem Verfall der Farbe verwirklicht werden. Es sind auch die Schrinken der Teilchen und der Isotherme der Sorption vorgestellt.

Caractéristiques du séchage des pois verts dans les lits fluidisés

Résumé: Un lit fluidisé modifié où l'air de fluidisation est la somme d'un fllux d'air continu et d'un flux d'air pulsé, un concept appelé lit fluidisé (LFP) a été développé pour éliminer certaines des limites des lits fluidisés (LF) conventionnels. Le séchage des pois verts a été réalisé afin d'établir les avantages du LFP. En raison du bon brassage des

pois créé par le flux d'air pulsé, le LFP a conduit à un taux de séchage supérieur de même qu'à une diminution de la dégradation de la couleur. Des résultats sur la réduction de la taille des pois et des isothermes d'absorption sont aussi présentés.