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Hydrodynamic behavior of a jet spouted bed of shrimp

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Abstract

Dried shrimp is one of the most important exported marine products of Thailand. The price of dried shrimp depends largely on its quality viz. dryness, color and size. To improve the quality of dried shrimp as well as to enhance the production capacity of the drying process a jet spouted bed dryer has been proposed to dry shrimp. Prior to being able to design and operate the dryer efficiently information on the dryer hydrodynamic behavior is needed. The present research therefore aimed at investigating the effects of various operating parameters, i.e., size of shrimp, bed height and nozzle diameter, on the bed hydrodynamic characteristics viz. minimum spouting velocity as well as maximum and steady spouting pressure drops. Empirical correlations that can be used to predict the flow behavior of shrimp, which is an irregular-shaped bioproduct, in a jet spouted bed dryer were also developed.

Keywords: Empirical correlations; Maximum pressure drop; Minimum spouting velocity; Moisture content; Spouting pressure drop

1. Introduction

Dried shrimp is one of the most important exported marine products of Thailand. Its price depends largely on its quality viz. dryness, color and size. In the traditional processing method shrimp is dried under the sun for 3–5 h, depending on the availability of sunshine. Based on the recent survey, however, it is reported that producers of dried shrimp are searching for dryers that have higher efficiency and are able to supply heat to shrimp uniformly and thoroughly without having to place the shrimp and let it dry in the sun, hence minimizing the labor cost and the possibility of product contamination.

The production of dried shrimp can be mainly divided into two steps: boiling (in order to deactivate microorganisms) and then drying. Several techniques have been used to dry shrimp with various degrees of success. Ramaswamy, Lo, and Statey (1982) studied the drying characteristics of shrimp using a pilot plant cabinet-type air dryer. It was found that the orientation of the flow of drying air (through-flow and cross-flow air circulation) significantly affected the drying time of shrimp. The water activity of dried shrimp at 27 °C was found to be less than 0.80, which is considered as the lower limit for the growth of most food spoilage microorganisms. Shrimp should therefore be dried to moisture content around 20% (w.b.) or 25% (d.b.). Posomboon (1998) studied the effects of salt concentration and boiling time on the final quality of dried shrimp and found that the salt concentration and boiling time of only 2% (w/v) and 2 min, respectively, are enough to reduce the number of microorganisms to an acceptable level. The effect of drying air temperature on the drying kinetics and quality of dried shrimp was also investigated by separating drying into three temperature ranges: low-temperature drying (40–70 °C), high-temperature drying (100–140 °C) as well as two-stage drying (120 °C and then 70 °C and 140 °C and then 70 °C). Low-temperature drying at 70 °C was recommended because less energy was consumed and color and sensory

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Nomenclature

c	longest intercept of shrimp normal to e and i, cm
D_c	column diameter, cm
D_n	nozzle diameter, cm
D_p	equivalent diameter, cm
D_{pgm}	geometric mean diameter, $(e \times i \times c)^{1/3}$, cm
e	longest intercept of shrimp, cm
i	longest intercept of shrimp normal to e, cm
H	bed height, cm
ΔP_{bed}	bed pressure drop, N/m^2
ΔP_{max}	maximum pressure drop, N/m^2
ΔP_s	spouting pressure drop, N/m^2
r^2	coefficient of correlation
U_{bed}	bed superficial velocity, m/s
U_{msn}	nozzle minimum spouting velocity, m/s
X_{in}	shrimp initial moisture content, % dry basis
X_t	shrimp moisture content, % dry basis
g	acceleration due to gravity, m/s^2

Greek letters

μ_g	fluid viscosity, kg/m s
ρ_b	bulk density, kg/m^3
ρ_s	shrimp density, kg/m^3
ρ_g	fluid density, kg/m^3
ϕ	sphericity, D_{pgm}/e

Dimensionless groups

Ar	Archimedes number, $[D_p^3 \rho_g(\rho_s - \rho_g)g]/\mu_g^2$
Re_{msn}	minimum spouting Reynolds number based on nozzle velocity, $D_p U_{msn} \rho_g/\mu_g$

quality of the dried product were acceptable. High-temperature drying at 140 °C adversely affected the color of dried shrimp and caused difficulties in deshelling due to the fusion of shrimp shell and meat. Two-stage drying with high drying air temperature in the first stage did not affect the color of dried shrimp although the energy consumption was higher than the low-temperature drying but lesser than the single-stage high-temperature drying.

There are many types of equipment that can be used to dry particulate food materials such as fluidized bed dryers (FBDs), which have found widespread applications for drying because of their high drying rates due to excellent gas-particle contact leading to high heat and mass transfer rates (Bobic, Bauman, & Curic, 2002; Hatamipour & Mowla, 2002; Hatamipour & Mowla, 2003; Izadifar & Mowla, 2003; Mujumdar & Devahastin, 2000; Senadeera, Bhandari, Young, & Wijesinghe, 2003). FBDs, however, suffer from several shortcomings, especially when particles to be processed are larger than 1000 microns. For these reasons, spouted bed dryers (SBDs) and jet spouted bed dryers (JSBDs) have been developed to dry large and difficult-to-fluidize, polydisperse particles, which are common characteristics of food products (including shrimp). These dryers have been used successfully to dry various food products, e.g., cereal grain (Zahed & Epstein, 1993) as well as roasting of food produces such as coffee beans (Nagaraju, Murthy, Ramalakshmi, & Srinivasa Rao, 1997) and barley (Robbins & Fryer, 2003). Jet spouted beds of inert particles have also been used to dry slurries and suspensions with success (Shuhama, Aguiar, Oliveira, & Freitas, 2003; Tia, Tangsathitkulchai, & Damronglaohapun, 1995).

In the present study experiments were performed to investigate the possibility of drying shrimp in a jet spouted bed dryer as well as to investigate the effects of various operating and geometric parameters of the dryer, i.e., size of shrimp, moisture content of shrimp, bed height and nozzle diameter, on the bed hydrodynamic characteristics viz. maximum pressure drop, steady spouting pressure drop as well as minimum spouting velocity. Empirical correlations that can be used to predict the flow behavior of a jet spouted bed of shrimp, which is an irregular-shaped bioproduct, were also developed.

2. Experimental set-up, materials and methods

2.1. Experimental set-up

A schematic diagram of the overall experimental set-up is shown in Fig. 1. The jet spouted bed was made of stainless steel with a column diameter of 20 cm and a cone angle of 20°. The air inlet nozzle was located at the center of the bottom cone. Two different nozzle diameters, 5 cm and 10 cm, were used in the study. A blower, which was driven by a 1.5 hp motor, was used to supply the spouting air to the bed. A fin heater rated at 9 kW was used to heat the air; the air temperature was measured by a type-k thermocouple and controlled by a PID controller. For the purpose of the hydrodynamic study, the spouting air temperature was set constant at 70 °C. The velocity of the air was measured at the inlet of the bed using a pitot tube. U-tube manometer was used to measure the pressure drop across the bed.

3. Materials

The tested material used in the present study was white shrimp in the genus *Penaeus spp*. Raw shrimp