Pet Food from Bovine Origin Drying by Green Heat Pump Technology and Fluidization

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Introduction

Fluidized bed drying is a gentle and efficient process to remove moisture (Geldart, 1986). Fluidization favors rapid heat and mass transfer by reducing the boundary layer between particles and air promoting rapid mixing (Senadeera et al., 1998). This is a convenient method for heat sensitive food materials. The Ergun equation (Ergun, 1952) holds for minimum fluidization velocity (Kunii and Levenspiel, 1991).

$$(1-\varepsilon_{mf})(\rho_p-\rho_f)g = 150\frac{(1-\varepsilon_{mf})^2}{\varepsilon_{mf}^3}\frac{\mu u_{mf}}{(\varphi d_p)^2} + 1.75\frac{(1-\varepsilon_{mf})}{\varepsilon_{mf}^3}\frac{\rho_f u_{mf}^2}{\varphi d_p} \tag{1}$$

The values obtained by the Ergun Equation are reliable for spherical and small particles. For larger particles of various shapes and sizes the Ergun values deviate from measured values. For larger particles and high Reynolds numbers (Re >1000) the fluidization is governed by the kinetic energy term in the Ergun Equation, which is simplified by (Kunii and Levenspiel, 1991):

$$u_{mf}^2 = \frac{\varphi d_p^2}{1.75}\frac{(\rho_p-\rho_f)}{\rho_f} g \varepsilon_{mf}^3 \tag{2}$$

The heat pump drying technology is environmental friendly and operates in a closed loop avoiding exhausted to atmosphere. The drawback of this technology is the low moisture removal rates due to longer residence times of stationary beds. This problem can be overcome by agitation, fluidization and intermittent drying (Mujumdar and Alves-Filho, 2003). Any drier that uses convection as the primary mode of heat input can be fitted with a suitably designed heat pump such as fluid bed dryers.

Heat pump fluid bed drying offers better product quality, offsetting incremental increasing in drying costs with a high market value of the product. Knowledge of drying kinetics is important in the design, simulation and optimization of the drying processes. Drying curves are usually modeled by defining the drying rates constants based on first order kinetics. The basic model of drying kinetics is known as the simple (exponential) model (Equation 3) given by the moisture ratio as follows:

$$MR = \exp(-kt) \tag{3}$$

Material and Methods

The raw material used was bovine intestine cut in cubicle particles. Samples were prepared by cutting them into 4 mm cubes and kept at -25^{o} C before drying to maintain original characteristics and heated close to melting point prior to drying.

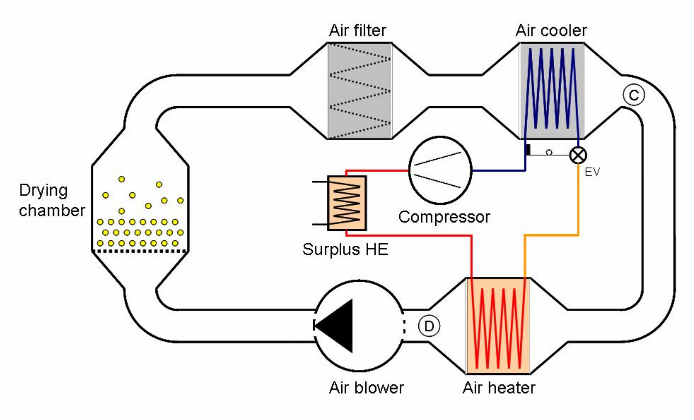

Figure 1. The lay-out of the green heat pump dryer with fluidization

The air enters the drying chamber and fluidized the wet material. The removed water from the material was condensed on the surface of the evaporator and was drained out from the loop. The dehumidified air flowed through the condenser and was heated and re-enter the drying chamber at the desired drying temperature. In this way the latent heat of removed water is used to boil the fluid inside the evaporator. The energy recovered is transferred to the air flow as the fluid liquefies inside the condenser. The external parts of the drying loop and heat pump circuit are thermally insulated to minimize energy losses to the surroundings (Alves-Filho et al., 2006). The lab dryer is shown in Figure 1 indicating the flow of air and refrigerant. The drying chamber is cylindrical with a diameter of 0.25 m, and particle bed height was kept at constant for all trials by using a bed volume of 2x13^{-3} m^{3} of material. The drying temperatures were -10, -5, 5, 15, 25^{o}C and combinations of -10/25^{o}C and -5/25^{o}C. All experiments were done under stable fluidization condition and fluidization velocity was kept at 1.5~2.5 m/s. Fluidized bed heat pump drying of bovine intestine samples were done in atmospheric pressure at below and above the material freezing temperature. Sampling and measurements were taken during each drying test to characterize quality and properties. To determine particle density, a known number of particles were weighed and, their volume was determined using volume displacement method. For bulk density, similar method was used by filling a container of known volume. Particle diameter and sphericity was calculated from initial dimensions of the product. Particle density and bulk density was used to calculate bed porosity at both initial and final conditions for all drying conditions.

Results and Discussion

Figure 2 shows initial and final particle classification in the Geldart chart. When drying proceeds the fluidization increases for all the drying conditions, which is due to changing of particle sphericity from 0.81 to about 1. Also, the change in fluidization velocity is related to variations in particle density, moisture content, shape, dimensions or shrinkage. Low value of bulk density (200 kg/m^3) at the end of drying compared to initial bulk density of 500 kg/m^3 and higher particle density at the end of drying (from 900kg/m^3 initially and 1100 kg/m^3 finally) is attributed to difference in shrinkage producing a very porous product.

Table 1 Minimum fluidization velocity (m/s)

T (^{o} C)	Ergun Model		Generalized Model		Experimental
	Initial	Final	Initial	Final	
-10	1.35	2.2	1.21	1.27	1.5~2.5
-5	1.36	2.22	1.22	1.28	
5	1.38	2.26	1.24	1.31	
15	1.4	2.29	1.26	1.33	
25	1.42	2.33	1.28	1.35	

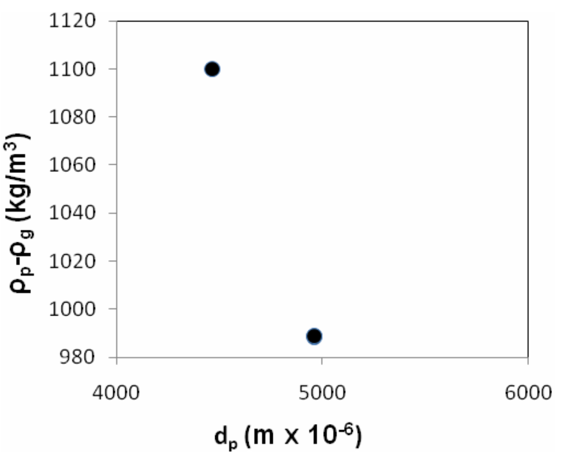

Figure 2. Particle class in Geldart chart

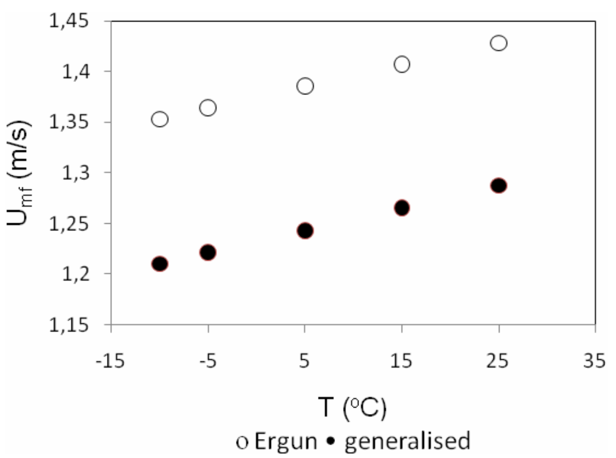

Figure 3. Calculated fluidization behavior

The minimum fluidization velocity by Ergun and generalized equations are shown in Figure 3 and the calculations are given in Table 1. When using the Ergun model a sphericity values was calculated based on measured dimensions of the bovine intestine particles and compared with the equivalent diameter of the particle. The particle fluidization changes progressively with temperature and as drying proceeds. Experimental values were 1.5 to 2.5 m/s and calculated Ergun values were from 1.35 to 2.33 m/s. the generalized model underestimated the minimum fluidization velocity at higher temperatures. Figure 4 shows the difference in initial and final fluidization velocities by Ergun Equation showed a linear trend with the temperature. The initial and final fluidization velocity is linearly correlated by

$$\Delta U_{mf} = 0.8683 + 0.0016T \quad (4)$$

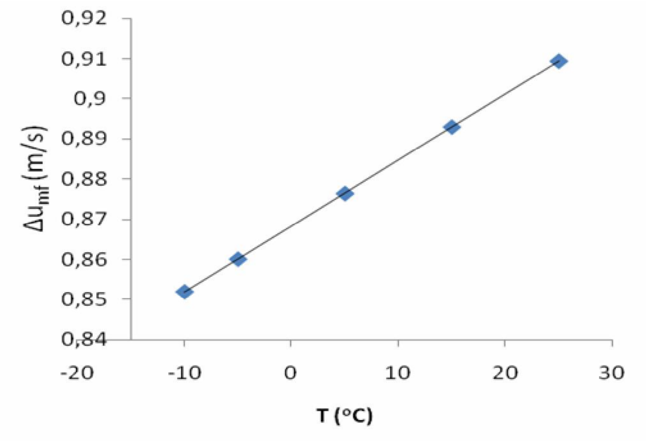

Figure 4. Fluidization velocity versus temperature

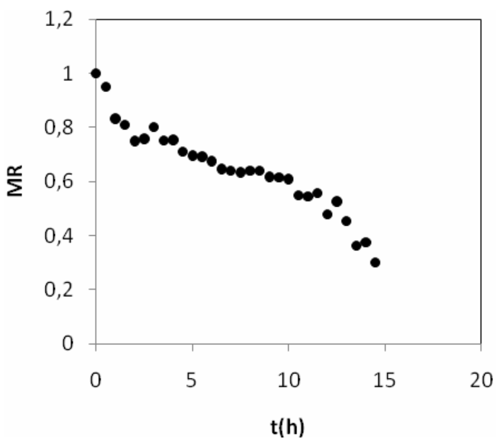

Figure 5. Drying kinetics at -10^{o}C

Figure 5 shows the drying kinetics of bovine intestine at -10^{o}C. Drying occurred mainly in the falling rate period for all experiment trials. Atmospheric freeze drying combined with medium temperature drying involve removal of moisture from solids both by sublimation and evaporation. In such combined process the moisture is removed sequentially by ice sublimation and liquid evaporation by avoiding structural collapse.

Conclusions

Fluidization behavior of the bovine intestine particulates changes as drying progresses. The calculated minimum fluidization with both Ergun and generalized equations confirm the experimental minimum fluidization velocities.

References

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