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FLUID-DYNAMIC PROPERTIES AND PRESSURE LOSS OF BLACK BEANS IN A PACKED BED

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ABSTRACT Fluid-dynamic behaviour based on physical properties of agricultural products is important in wide applications to handle and process those products. In this research work, the effect of several lengths (L): diameter (D) ratios of black beans bed and of air velocity on fluid-dynamic behaviour were studied. The equipment used was a fluidized bed chamber, which consists in a 150mm cylindrical column by approximately 1000mm of height and a flat perforated base. A frequency inverter controlled an electric centrifugal fan and air velocity. Black beans porosity was calculated by relation between solid and bulk densities. Bulk density was determined by filling a graduated beaker with a weighted portion of black beans. The void volume was full filled with distilled water. Solid density is the ratio between immersed mass and free void sample volumes. The experimental runs for fluid-dynamics behaviour consisted of determining the pressure loss of increasing and decreasing the air flow and the expansion of black beans bed for different L:D ratios. The minimum fluidization velocity U_{mf} was determined in each experimental run by characteristic curves of pressure loss, which were obtained by variation of air velocity through the black beans bed. U_{mf} values were about 2,0 m.s^{-1}.

Keywords: porosity, air flow, fluidization, minimum fluidization velocity.

INTRODUCTION Fluidization is the operation by which solid particles are transformed into fluid-like state through suspension in a gas or liquid (Kunii and Levenspiel, 1991). This is achieved by pumping a fluid, either a gas or a liquid. upwards through the bed at a rate that is sufficient to exert a force on the particles that exactly counteracts their weight; in this way, instead of a rigid structure held in place by means of gravity-derived contact forces, the bed acquires fluid-like properties, free to flow and deform, with the particles able to move relatively freely with respect to one another (Gibilaro, 2001).

Heat, mass and momentum transfer phenomena are usually associated to fluidization. Heat and mass transfer occurs very easily due to the rapid mixing of particulate solids, corresponding to high transfer coefficients.

Drying in fluidized beds is used extensively in a wide variety of industries because of its good performance, low investment and maintenance costs and high thermal efficiency (Kunii and Levenspiel, 1991). Many different types of materials, from chemicals to foodstuffs and from plastics to fertilizers, are treated in this way, usually with large throughputs in the continuous mode of operation (Kettner et al., 2006).

Fluidized bed dryers are widely used in industry in both continuous and batch forms.

Accomplished studies suggested some necessary adjustments for operational optimization of the dryer, as analyses of the solids behavior in dryer bed, effects of the vibration in the drying rate and pressure drop. Those parameters are of vital importance in the drying system design, providing the appropriate drying rate and higher efficiency of the dryer.

Eventually this kind of information can be used to obtain closure information required for appropriate operation of a laboratorial or industrial fluidized bed dryer.

Fluidization Fluidized bed dryers have found widespread applications for the drying of particulate or granular solids in the chemical, food, ceramic, pharmaceutical, agriculture, polymer, and waste management industries. Suspensions, solutions, dilute pastes, or sludges are atomized into a fluidized bed of inert particles and the dry powder is separated from the exhaust gases (Yang, 2003).

Unless reliable data exist for the same product it is strongly recommended that laboratory scale tests be carried out to verify that the material can be processed in a fluidized bed. Ozahi et al. (2008) stated that the determination of pressure drop through a bed as a function of some variable of process as fluid flow rate or geometrical constraints of the bed or physical properties of bed material is very critical for selection and use of an optimum pump or fan. The conditions for fluidization (e.g., minimum fluidization velocity) may be estimated using published correlations, but serious errors may accrue due to the surface wetness of the particulate solid, which may generally behave entirely differently from a surface-dry particle (Yang, 2003).

Some authors have described some of advantages and disadvantages of fluidized beds. Some of advantages include:

- Liquid like behavior, easy to control and automate;

- High rate of heat and mass transfer conditions;

- Rapid mixing, uniform temperature and concentrations;

- It is suitable for accomplishing heat-sensitive or exothermic or endothermic reactions;

- Circulate solids between fluidized beds for heat exchange;

- The system offers ease of control even for large-scale operation;

- Good mixing conditions.

The disadvantages of fluidized beds include:

- Fluidized beds of fine-sized particles are difficult to predict and are less efficient,
- Rapid mixing of solids causes non-uniform residence times for continuous flow reactors,
- Modeling and scaleup are difficult;
- Elutriation of fines and power consumption due to pumping are inevitable;
- Severe erosion of immersed surfaces due to collisions by particles.

Pressure loss in fixed and fluidized bed Gibilaro (2001) describes that when a particles bed is submitted to a rising fluid flow through this bed, this fluid loses energy due to frictional dissipation, resulting in a loss of pressure that is greater than can be accounted for by the progressive increase in gravitational potential energy.

Gupta and Sathiyamoorthy (1999) stated that when a gas passes through a fixed bed of particulate solid, the resistance to its flow, in addition to various hydrodynamic parameters, depends on the previous history of the bed, that is, whether the bed under consideration is a well-settled bed or a well-expanded and just settled bed.

The total drop in fluid pressure across a particle bed can be considered as result of the fluid-particle frictional interaction and the gain in gravitational potential energy in the rising fluid. This energy is dissipated as heat due to the irreversibility of frictional processes.

It is clearly important to be able to estimate this additional energy requirement, and considerable research effort has been expended for this purpose.

Figure 1 illustrates the relation between fluid velocity and pressure loss in fixed and expanded bed. It also illustrates that, in practice, the transition between the fixed and fluidized states involves some particle rearrangement, with the breakdown of bridging structures, which are inherent in the initial packing and subsequent defluidization operations; rather than an abrupt change in slope at the minimum fluidization velocity U_{mf}, a more gradual approach to the constant pressure loss is observed in practice, often with some overshoot in the transition region (Gibilaro, 2001).

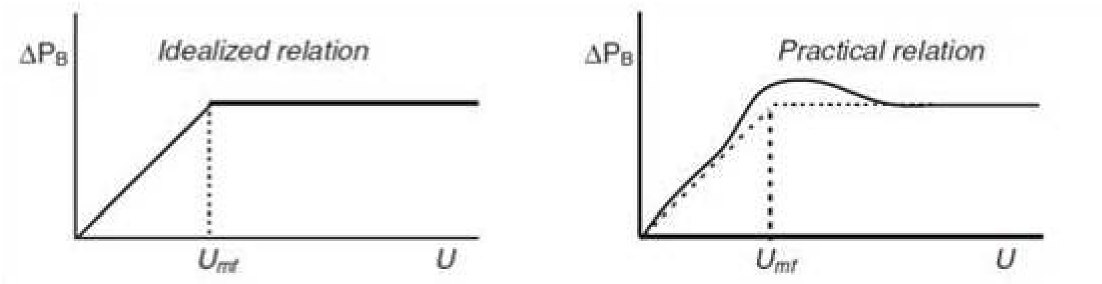

Figure 1. Unrecoverable pressure loss in a fluidized bed (Gibilaro, 2001).

A positive relative variation of ε causes a negative variation in the pressure drop multiplied by a factor that is dependent on the void fraction ε and on the slope of the Reynolds number (Achenbach, 1995).

MATERIAL AND METHODS

Material The material used in pressure loss determination was black beans purchased in a food commercial store. The porosity ε of black beans was calculated by the relation between bulk and apparent densities. Bulk density (ρ_b) was determined by filling a graduated beaker with a weighted portion of black beans. The residual volume was full filled with distillated water. Apparent density ρ_{ap} is the ratio between the immersed mass and the free void sample volume.

Fluidized bed dryer The pressure drop experimental runs were accomplished in a fluidized bed dryer apparatus conjugated to a crossflow and parallel flow convective dryer. This apparatus consisted in a glass tube joined to dryer pipes. The fluid bed chamber has a cylindrical body of 150mm of diameter by approximately 1000mm of height and a flat perforated base. There were valves by which the air con be forced to pass through the black beans bed.

A frequency inverter was responsible to control the blower rotation and adjust it in predefined air velocities. The pressure loss measurements were obtained by an “U” tube manometer engaged below a perforated plate which contains granular bed and above black beans bed (in the glass tube). The air velocities were verified during experimental runs by a vane anemometer. The curves of pressure loss in function of air velocity were constructed for different length (L): diameter (D) ratios.

RESULTS AND DISCUSSION

Material physical properties Some physical properties of black beans were determined (Table 1). These properties allow the experimental material characterization.

Table 1. Physical properties of black beans.

Physical property	Experimental data
Average diameter d	0.00686 m
Bulk density ρ_b	820.8 $kg.m^{-3}$
Apparent density ρ_{ap}	1286.9 $kg.m^{-3}$
Porosity ε	0.362

The pressure loss curves for different black beans bed lengths were developed based on methodology previously mentioned. These experimental curves are shown on the Figures 2 to 5:

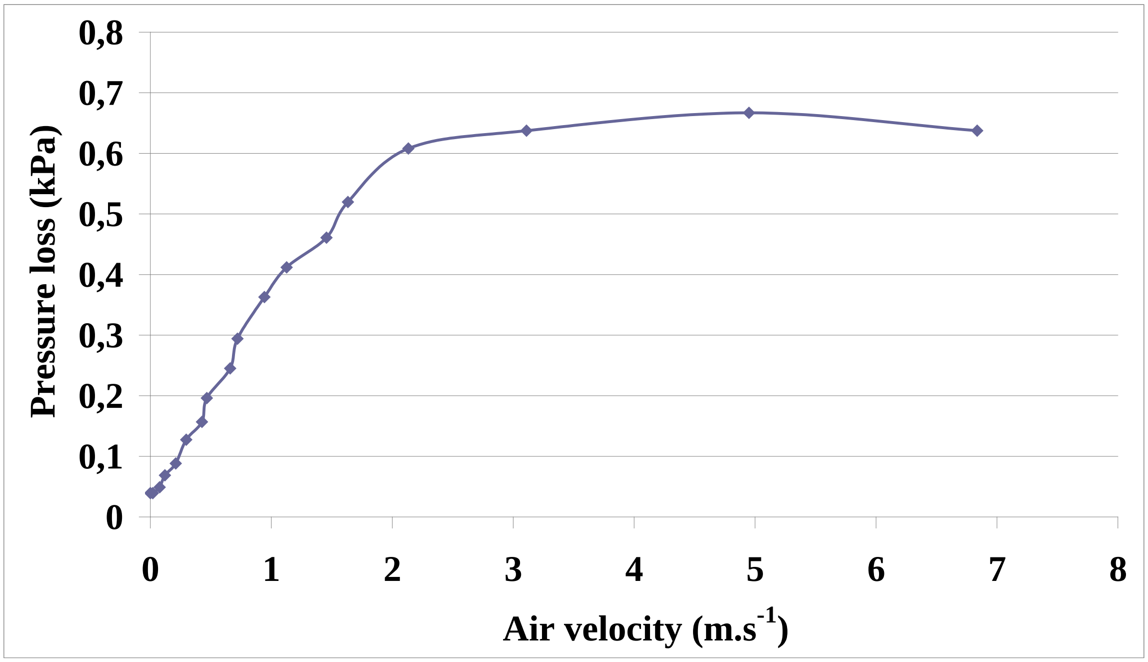

Figure 2. Pressure loss of black beans bed in function of air velocity – 0.08m length.

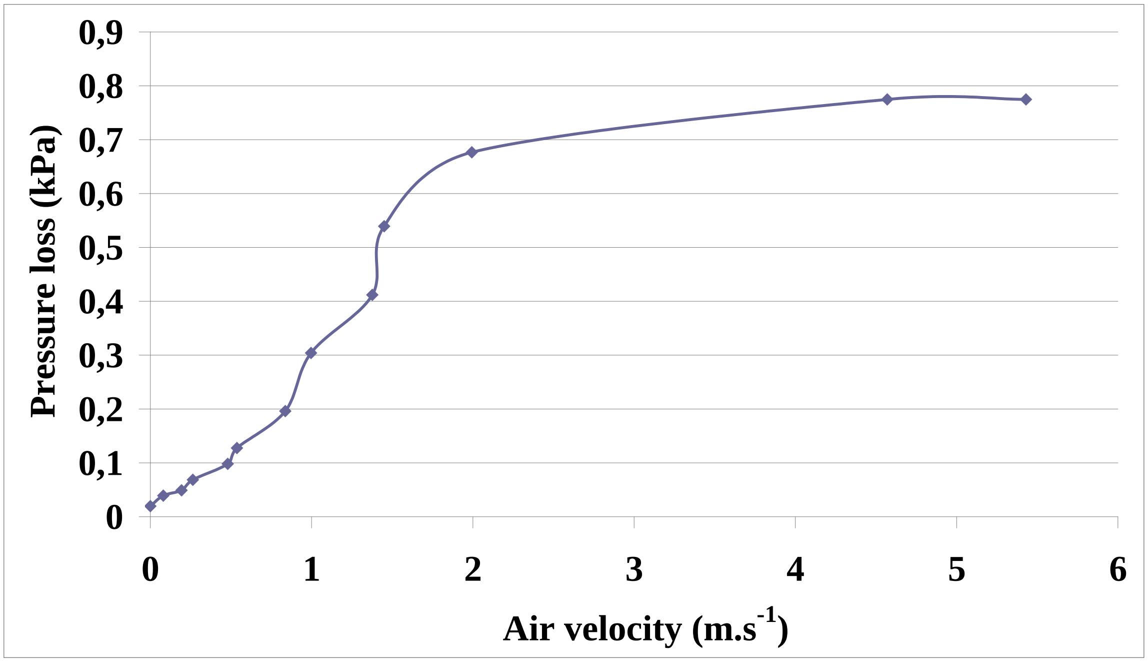

Figure 3. Pressure loss of black beans bed in function of air velocity – 0.10m length.

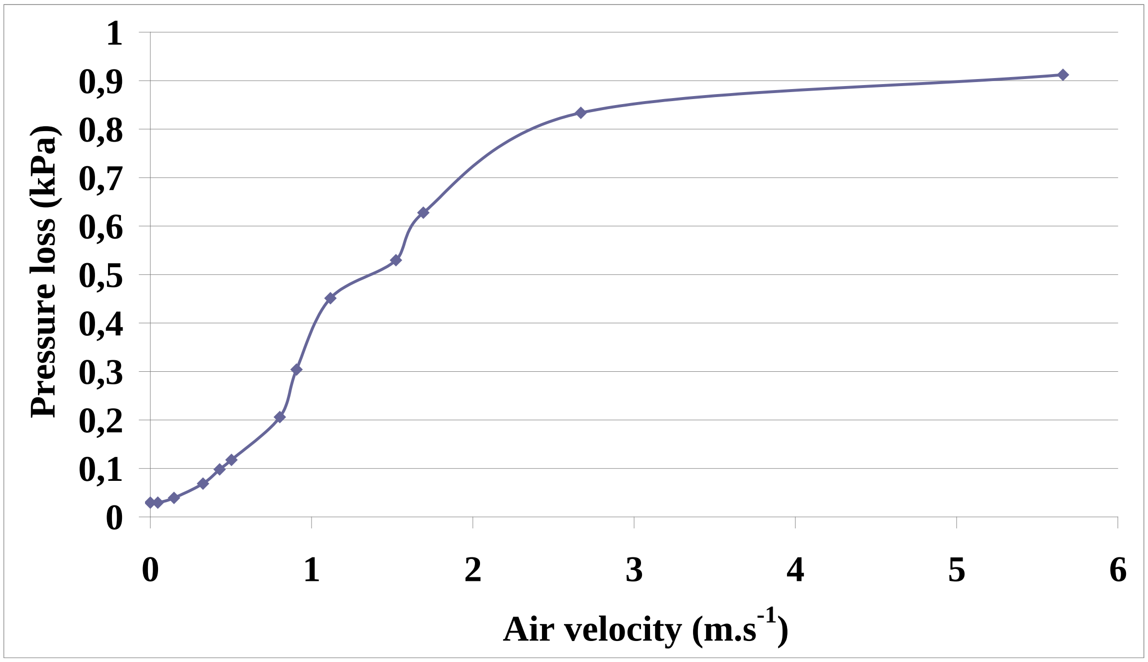

Figure 4. Pressure loss of black beans bed in function of air velocity – 0.12m length.

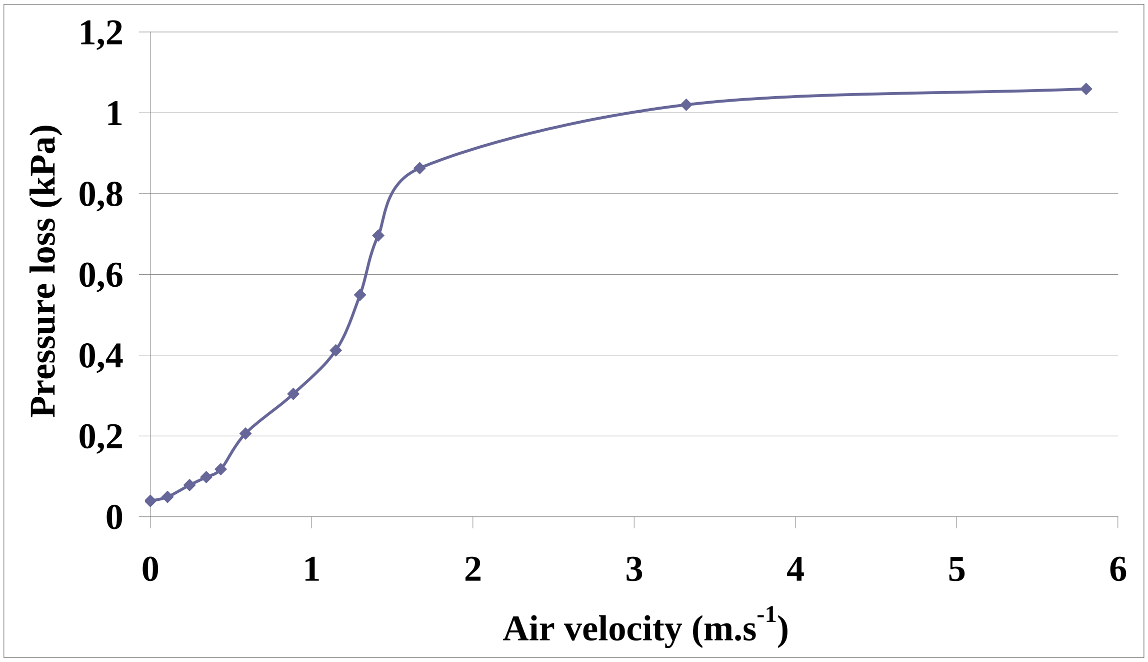

Figure 5. Pressure loss of black beans bed in function of air velocity – 0.14m length.

We can notice that all curves keep their crescent variation during fixed bed period with a higher inclination of the 0.14:0.15 curve. The relative constant pressure losses of the fluidized bed period increased with the increment on the L:D ratio. It means that the pressure loss of fluidized beds with higher bed lengths was higher than lower bed lengths. While pressure loss of 0.08m curve was about 0.65kPa, the 0.14 curve reached approximately 1.05kPa.

Mowla and Souraki (2006) identified slugging and channeling as common phenomena for fluidization of green beans. The authors also mentioned the effect of increasing L:D ratio in channeling and slugging prominence.

Graphically, minimum fluidizing velocity can be obtained by analysis of the inflexion in the pressure drop curve. Thus, U_{mf} was estimated for each experimental run by graphical analysis of pressure loss versus air velocity. The first part of the curves approximates to a crescent linear function, while the second part presents approximately constant values for pressure loss. The intersection of these curves were considered a estimative for minimum fluidizing velocity for each L:D ratio.

Table 2. Minimum fluidization velocity for black beans bed.

Length:Diameter ratio	Minimum fluidization velocity ($m.s^{-1}$)
0.08:0.15	2,00
0.10:0.15	2,07
0.12:0.15	2,30
0.14:0.15	2,01

It can be noticed that all the results presented U_{mf} values oncoming 2 $m.s^{-1}$, except for 0.12 m length curve.

CONCLUSION Curves of pressure loss in function of air velocity were obtained. These curves resemble to typical curve for fixed and fluidized particle bed. However, the experimental curves did not presented the overshoot usually presented in the inflection point of practical relations.

Related to pressure loss in fluidized bed, it can be noticed that the maximum pressure loss varied in function of bed lengths. Minimum fluidization velocity values were approximately 2 $m.s^{-1}$, except for 0.12:0.15 ratio.

For fixed bed, it was observed a non-linearity behavior in increasing of pressure loss. Possibly, the air flow had passed through black beans bed by preferential channels. In some cases, it was visually detected.

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