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Numerical and experimental study of an innovative pipeline design in a granular pneumatic-conveying system

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ABSTRACT

During gas–solid mixture conveying in a dense phase, material is conveyed in dunes on the bottom of the pipeline, or as a pulsating moving bed. This phenomenon increases the pressure drop and power consumption. We introduce a new technique to reduce the pressure drop, which is termed the perforated double tube. To validate this new model, the gas–solid flow pattern and pressure drop were studied numerically and experimentally. The power consumption was also studied experimentally. Numerical studies were performed by the Eulerian–Lagrangian approach to predict gas and particle movement in the pipeline. Comparisons between the numerical predictions and the experimental results for the gas–solid flow patterns and pressure drop show good agreement.

Introduction

Pneumatic-conveying systems are applied widely to transport many powder and granular materials. In agriculture, high volumes of harvested products, such as grains, processed materials, animal feed pellets, and chemical fertilizers; and food products such as flour, sugar, tea, and coffee can be transferred by this method (Mills, 2004). The performance of pneumatic-conveying systems is influenced by a wide range of parameters, such as the material, fluid properties, the mode of conveying, and the physical conveying conditions.

In dense-phase mode for high solid mass flow rates, blockages can occur in the pipe and the pressure drop and power consumption increase. By-pass and air-injection systems have been proposed as a solution to this problem (Mills, Jones, & Agarwal, 2004).

Several studies have been conducted to evaluate conventional pipeline and by-pass systems in pneumatic conveying, which include many important topics such as the pressure drop, power consumption, material behavior, and computational-fluid-dynamics (CFD) analysis (McGlinchey & Cowell, 2008; Laín & Sommerfeld, 2008; Y. Zhang et al., 2010). However, few studies have been conducted to develop a new technique for pipelines. Therefore, a new pipeline design is necessary to optimize the conveying process. This research documents an experimental and numerical study for an optimized pipeline.

Material and methods

Corn and barley were chosen for testing the developed system, because cereals have a high transport volume. To study the effect of air velocity on pressure drop and power consumption, a suction pneumatic-conveying system was designed and developed. The pneumatic-conveying system consisted of a centrifugal blower, a seed hopper, a rotary airlock, intake and discharge pipes, a separator cyclone, and a discharging cyclone as shown in Fig. 1 (Ghafori, Hemmat, Borghaee, & Minaei, 2011). The choice of power source and vacuum blower were based on the ability of the blower to provide adequate suction and discharge pressures to overcome pressure losses (air friction losses, losses from grain acceleration, grain lift, and grain flow) in the system. The seed hopper served as a storage container for the material. Seeds to be conveyed were introduced into the system using a gate feeder under the hopper. The gate feeder was adjusted to feed seeds at a constant rate. Before the test, the gate feeder was calibrated according to the feed rate. The system was designed for a 30 t/h capacity with an 8-m long horizontal pipe, a 10-m long vertical pipe with an internal diameter of 15 cm and four bends. The pipeline (flexible pipe and perforated double tube) was Plexiglas so that the behavior of the seeds could be compared when material was conveyed through the pipeline.

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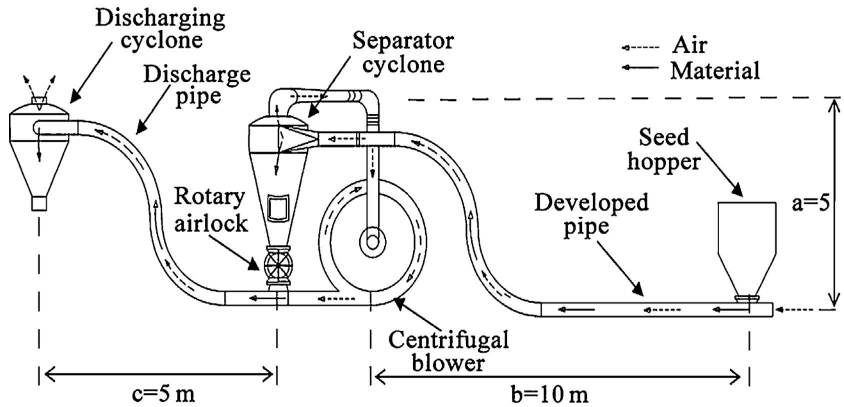

Fig. 1. Arrangement of pneumatic-conveying system (Ghafori et al., 2011).

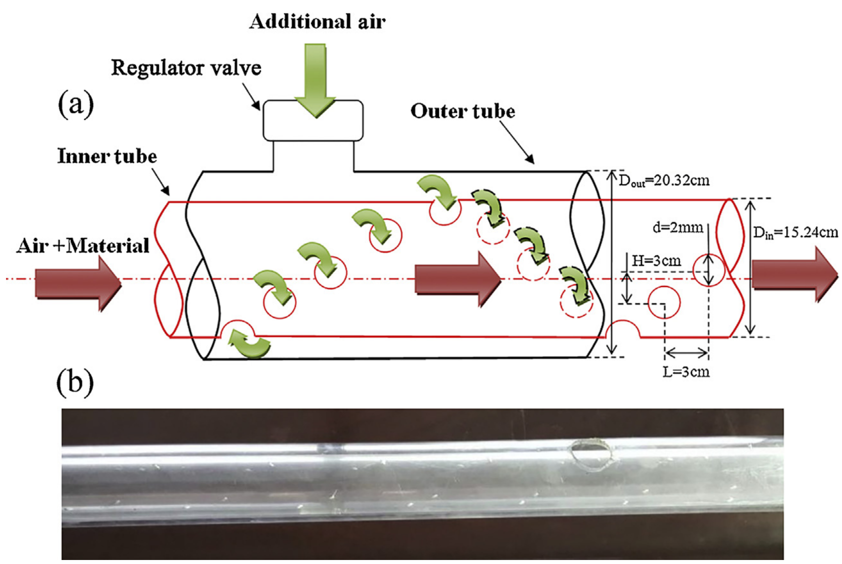

Fig. 2. (a) Schematic and (b) photograph of perforated double tube.

Design and development of optimized pipeline

To reduce friction between the material and the pipe wall, a perforated double tube was designed and developed to add air along the pipeline during the material-conveying process. The perforated double tube was made from two coaxial pipes of 15.24 and 20.32 cm diameters. Holes with a 2-mm diameter and in a spiral pattern were established on the inner tube wall as shown in Fig. 2. A vent was placed on the outer tube to allow additional air to be sucked through this vent. The additional air flow rate was controlled by a regulator valve, which was located on the vent inlet. The regulator valve was normally closed and it also closed when only air was conveyed along the pipe. When material conveying was initiated, the pressure drop began to increase and the regulator valve began to open because of the pressure drop in the pipeline. At this point, additional air filled the space between the two pipes. While material was conveyed along the suction line, additional air was sucked through the vent into the space between the pipes and then it flowed through the holes into the inner tube.

Experimental measurements

Because the shape, size, volume, density, and porosity are important in the analysis of the behavior of the seeds when handling material (Güner, 2007; Molenda, Horabik, Thompson, & Ross, 2004), in this study, the initial physical properties of corn and barley seeds such as length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity, volume, thousand seed mass, moisture content, bulk density, actual density, porosity, and projected area were determined (ASAE, 1999; Dursun & Guner, 2003; Kibar & Ozturk, 2008; Tabak, Biran, Tabak, & Manor, 2002; Yalçın & Özarslan, 2004) (Table 1).

Table 1
Mean and standard deviations of seed physical properties.

Physical properties	Corn	Barley
Moisture content (%, w.b.)	10.55 ± 0.40	5.97 ± 0.38
Length (mm)	12.18 ± 1.09	9.78 ± 1.08
Width (mm)	8.78 ± 0.47	3.41 ± 0.27
Thickness (mm)	5.12 ± 0.99	2.77 ± 0.24
Arithmetic mean diameter (mm)	8.69 ± 0.33	5.32 ± 0.49
Geometric mean diameter (mm)	8.13 ± 0.42	4.52 ± 0.38
Sphericity (%)	67.35 ± 0.6	46.36 ± 2.6
Volume (mm^3)	208.36 ± 51.39	29.19 ± 7.44
Projected area (mm^2)	52.07 ± 5.37	16.12 ± 2.75
Aspect ratio (%)	72.58 ± 7.35	35.05 ± 2.73
Thousand seed mass (g)	260.54 ± 10.73	30.17 ± 3.06
Bulk density (kg/m^3)	650 ± 10.64	648 ± 13.01
Actual density (kg/m^3)	1148 ± 14.14	1297 ± 17.96
Porosity (%)	43.32 ± 1.38	50.03 ± 1.13
Terminal velocity (m/s)	13.85 ± 0.53	7.84 ± 0.45
Drag coefficient	0.55 ± 0.04	0.4 ± 0.02