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PNEUMATIC CONVEYING OF WHEAT FLOUR: SYSTEM OPTIMISATION THROUGH PILOT TESTING

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Wheat flour is made from grinding and/or milling of wheat used for human consumption. As an effective transfer technique, pneumatic conveying is used to transfer wheat flour products within production plants. Because of the potentially explosive nature of flour dust, suppression and collection are of vital importance when transporting flour. In addition to containing dust, an understanding of the flow properties of flour is important for its successful transport. The characteristics of flour vary, depending on the type of material milled to make the flour, the climate indigenous to the region the material grew in and the methods used to mill the material(s) into flour. The present study focuses on optimization of wheat flour conveying systems through scaling up of pilot tests data of different wheat products. The experimental findings of pilot tests with two different wheat qualities (fine and coarse) are presented. The pilot test results are used in optimizing an industrial wheat handling plant using published scaling up technique [1, 2]. Conveying system performances are analysed in terms of transport rate and air volume flow rate, thus energy consumption.

KEY WORDS: bulk materials, pneumatic conveying, wheat flour, system optimisation.

1. INTRODUCTION

Pneumatic conveying is a material transportation process, in which bulk particulate materials are moved over horizontal and vertical distances within a piping system with help of an air stream. Using either positive or negative pressure of air or other gases, the material to be transported is forced through pipes and finally separated from the carrier gas and collected at the desired destination.

In recent years, pneumatic transport systems are being used much more often, acquiring market sectors, in which other types of transport were typically used. This mode of bulk solid transportation holds an important position in many industrial fields, because of a series of advantages over other modes of transportation; flexibility of installation, low material loss and dust emission (thus, environment pollution), reduction of capital and installation costs, low maintenance costs, repeated usage of conveying pipelines, easiness in control and automation are among the favourable advantages. Although pneumatic conveying has seen increased use in many industrial sectors, there are still many major problems hampering its employment in a wider range of industrial applications; high energy consumption, excessive product degradation and system erosion, unstable plugging phenomena, severe pipe vibration and repeated blockages are experienced frequently.

Various flow regimes exist inside the pipeline in a pneumatic conveying system, straddling the entire range of conveying conditions from extrusion flow (packed bed) to fully dilute suspension flow. Through numerous experimental studies together with visual observations using glass tubes, etc., scientists have concluded on these varieties of flow regimes. It has been seen that these different flow regimes could be explained easily in terms of variations of gas velocity, solids mass flow rate and system pressure drop.

2. THEORETICAL BACKGROUND

The strong dependence of the possible mode of pneumatic transport on the nature of the material to be conveyed plays a significant role in the design of a pneumatic conveying system. Unfortunately, there exists no reliable technique for characterisation of particulate materials, which can be readily used for the design of pneumatic conveying systems as available nowadays.

POSTEC has developed a scaling up technique for system design [1, 2]. In this approach, a representative sample of product is tested in a laboratory scale pneumatic conveying test rig (pilot plant) over a wide range of operating conditions. The product mass flow rates, air volume flow rates and resulting pressure drops are measured. Additionally, the minimum conveying conditions and blocking limits are also observed. This approach has the advantage that real test data on the product to be conveyed in the proposed system is used for the design process. Thus, it gives a high reliability level about the effects of product type, providing useful information on conveyability of the product. On the other hand, this approach gives good results for the determination of specified conveying limits like minimum conveying velocity, pressure minimum conveying, etc.

The well-known Darcy's equation could be modified for the two phase flow, which is experienced in pneumatic conveying systems by considering the gas-solids flow as a mixture having its own flow characteristics [1, 2]. As new inputs, pressure drop coefficient; K, solid suspension density; ρ_{sus} and entry velocity; v_{entry} were introduced. The total pressure drop of the conveying line was addressed in discrete way by considering horizontal and vertical straight pipe sections, bends and other pipe accessories like valves separately.

Darcy's Equation is thus modified for the pressure drop of a straight pipe section as shown below;

$$\Delta p_{st} = \frac{1}{2} K_{st} \rho_{sus} v_{entry}^{2} \frac{\Delta L}{D} \tag{1}$$

Equation 1 is directly applicable for the straight pipe sections irrespective of whether they are vertical or horizontal. For the pressure drop due to bends, the equation in a slightly different form has been used;

$$\Delta p_b = \frac{1}{2} K_b \rho_{sus} v_{entry}^2 \tag{2}$$

It should be highlighted that the v_{entry} value is the true gas velocity at the entry section of the concerned pipe section or pipe component.

The suspension density, ρ_{sus} can be defined as the mixture density when a short pipe element is considered. As an equation, it can be presented in the following way.

$$\rho_{sus} = \frac{m_s + m_a}{V_s + V_a} \tag{3}$$

The concept of suspension density becomes more rational as the considered pipe section becomes shorter. Practically, it is difficult to measure the pressure difference between two points that are not at least one metre apart. Thus, the maximum allowable distance between the two consecutive pressure points to have a reliable *K* has been defined as two metres.

It has been recognised that the pressure drop coefficient *K*, has a special correlation with entry section velocity, v_{entry} of a pipe component. Also, it has been found that this correlation is independent of pipe size. These findings were the foundation for the scaling up technique for the pipeline pressure drop.

In addition to the pressure drop, the minimum conveying air velocity is also one of the key parameters in the pneumatic transport of particulate bulk materials. An unnecessarily high conveying velocity will result in higher energy costs due to an increased pressure drop in the system, solids degradation, and pipe erosion that can result in an economically unattractive operation. On the other hand, systems designed with extremely low conveying velocities or extremely high solid flow rates are subject to erratic operation due to solids deposition or they may be completely inoperable because of blocking. Keeping gas velocity above minimum conveying velocity in all horizontal sections of a pipeline ensures no deposition of solids in the system and a continuous, safe and steady transport. It was be possible to find a model to predict the minimum conveying velocity using material properties and few flow properties [1, 2].

The concept of pressure drop scaling up technique and minimum conveying velocity determination together with some models to determine the entry section pressure drop formulate the software called 'PneuDesign', which can be used to design a completely new system or optimise an existing plant.

3. EXPERIMENTAL SET-UP

Under the current study, pneumatic conveying tests were conducted using the pilot scale test facilities available in the powder research laboratory ('Powder Hall') of the Dept. of POSTEC, Tel-Tek. A test rig was designed for handling the research activities on dilute phase conveying. Figure 7 shows a schematic diagram of the test rig.

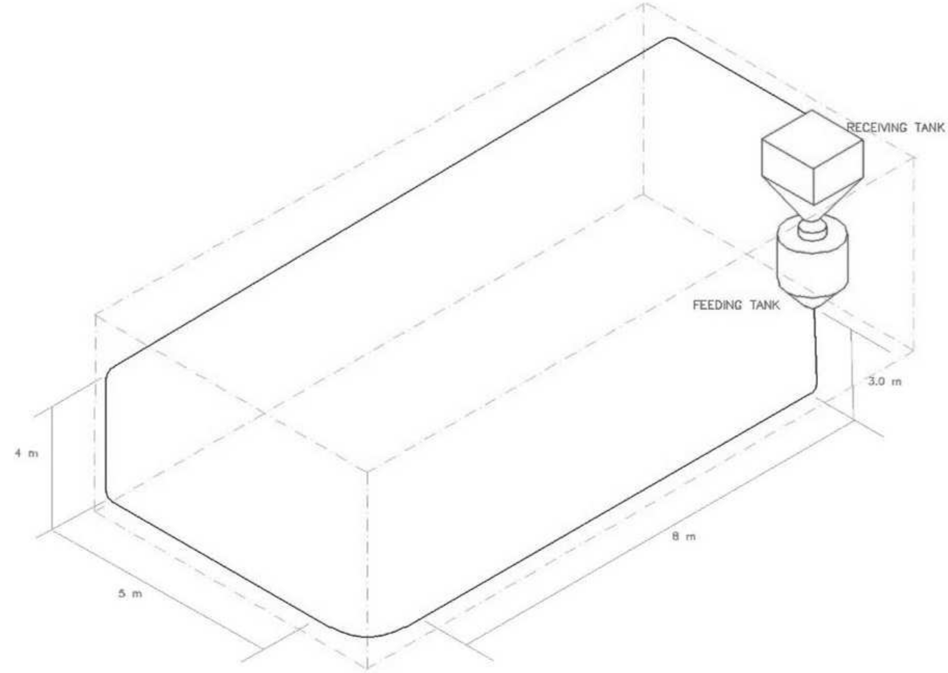

Figure 7: The schematic view of the conveying test rig

The test rig mainly consists of a discharge tank of 2.5 m^3 capacity, a receiving tank, which is mounted on a special arrangement of load cells to monitor the weight accumulation, and pipeline of 75mm diameter and approximately 40m length. The feeding from discharge tank to conveying pipeline was done by a rotary type feeder, whose feeding rate is regulated by a frequency controller. The pipeline consists of different pipeline components; horizontal straight pipes, a vertical pipe section and 90° standard bends. The conveying line forms a closed loop pneumatic transport circuit by placing the receiving tank on top of the feeding tank so that the wheat products could be repeatedly transported without taking out of the test rig. The air supply was received from a combination of a screw type air compressor and a drier/air cooler. The pressure and volume flow rate of supply air could be controlled by a regulator.

Number of different measuring instruments; pressure transducers and flow transducers were mounted on the transport line to achieve the desired pressure and air volume flow measurements. The transport rig is equipped with facilities for continuous online data logging and visualising of data like air pressure at various locations, air volume flow rate, material transport rate etc., on a real-time basis.

4. TEST MATERIAL

Two wheat flour qualities were tested under the current investigation; named as "Fine" and "Grove" qualities. The particle size distribution (PSD) measurements on samples of wheat products were carried out with a laser diffractometer ("HELOS & RODOS"). The result for “Fine quality” is shown in Figure 2. The measured properties of wheat products are given in Table 1.

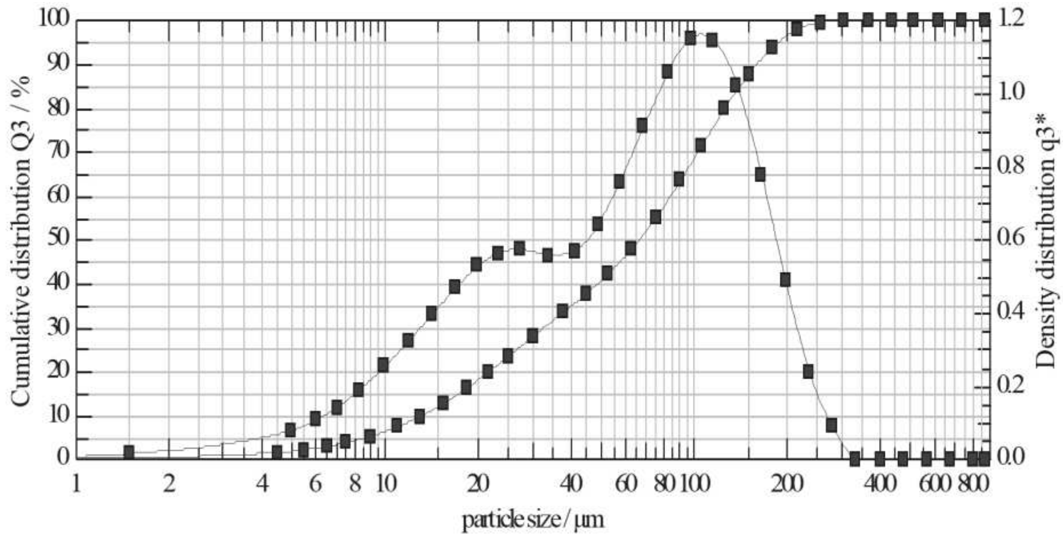

Figure 8: Particle size distribution of "fine" quality

Table 1

Properties of tested wheat products

Property		Fine quality	Grove quality
Mean particle size (d_{50}) (µm)		66.5	168.6
Bulk density (kg/m³)	Loose poured	465.6	568.1
	Tapped	649.9	667.5

5. EXPERIMENTAL PROCEDURE

Each wheat product quality was pneumatically transported several times through the test loop and a set of characteristic curves were generated based on the test results for a given pipe layout. To obtain the characteristic curves, the material was transported with a given supply air pressure and using various air flow rate conditions. During the test series, attempts were made to test wheat products in extreme conveying conditions, i.e., extremely dilute and dense conditions, by varying the feeding rate of solids to the conveying line. For each test run pressure data was recorded for every transducer placed on the pipeline at various locations. Air volume flow rate and solids flow rate were also recorded.

The supply air pressure was adjusted to a predetermined pressure and when the pressure is stabilised, the rotary feeder was switched on and material was introduced to the pipeline. One test run was carried out for a certain period to achieve steady conveying condition. The same procedure was followed for different solids feeding rates. The various test data sets were recorded using LabVIEW program and were later analysed for steady state flow conditions. These test data sets were then utilised for characterisation of the individual pipe elements and then the outcome was used to formulate the design and simulation calculation programme.

6. RESULTS AND DISCUSSION

During the conveying test series, both qualities of wheat products could be transported in pilot conveying test rig under different conveying conditions. Both qualities have shown quite similar performances under similar conveying conditions. A typical variation of different signals during a conveying test is shown in Figure 9.

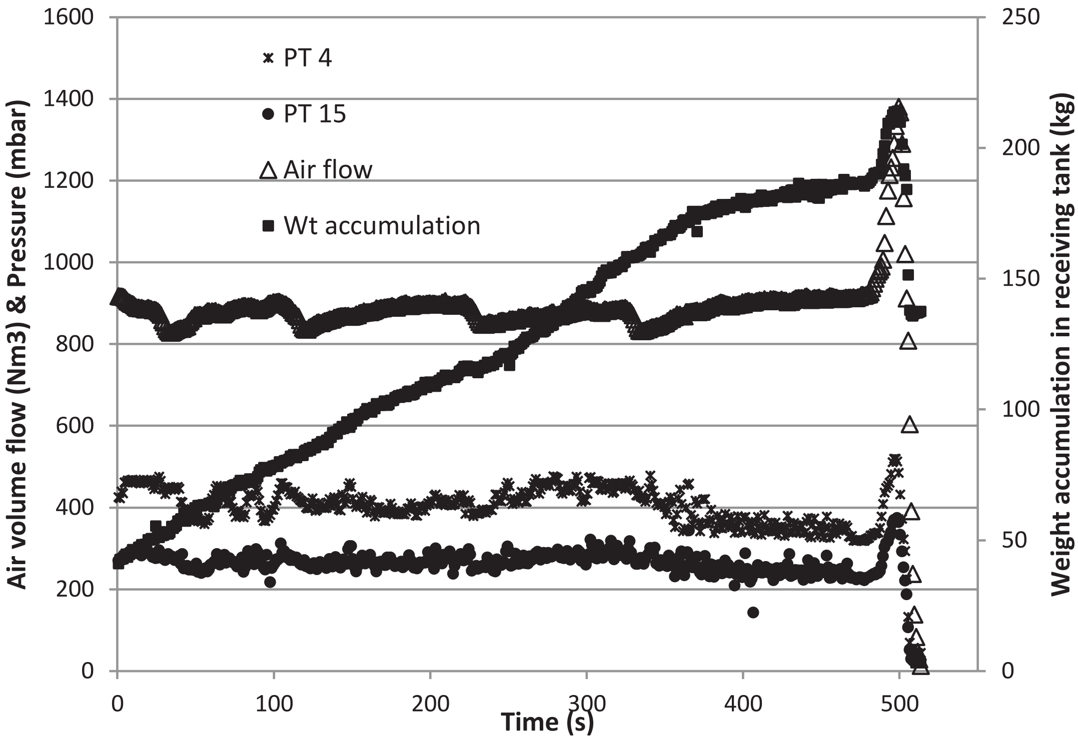

Figure 9: Variation of different signals during typical conveying test run

As one can see in Figure 9, the pressure signals were quite stable during a conveying run. In load cell signal, different gradients could be seen, when feeding rate of conveying materials was changed by varying the frequency of the rotary feeder. Under conveying runs with low air volume flow rates, it could be observed higher variations in pressure signals. Further reduction of air volume supply, the pipeline was blocked. This situation was used to determine the minimum conveying velocities of two wheat products.

The minimum conveying velocity (MCV) and solids loading ratios (weight ratio between solids and air) for both qualities were calculated based on the test measurements and are shown in Table 2.

Table 2

Minimum conveying velocity and test range of solids loading ratios of wheat products

Measurement		Fine quality	Grove quality
Minimum conveying velocity (v_{min}) (m/s)		8.1	11.8
Solids loading ratio	maximum	13.1	6.8
	minimum	0.8	0.8

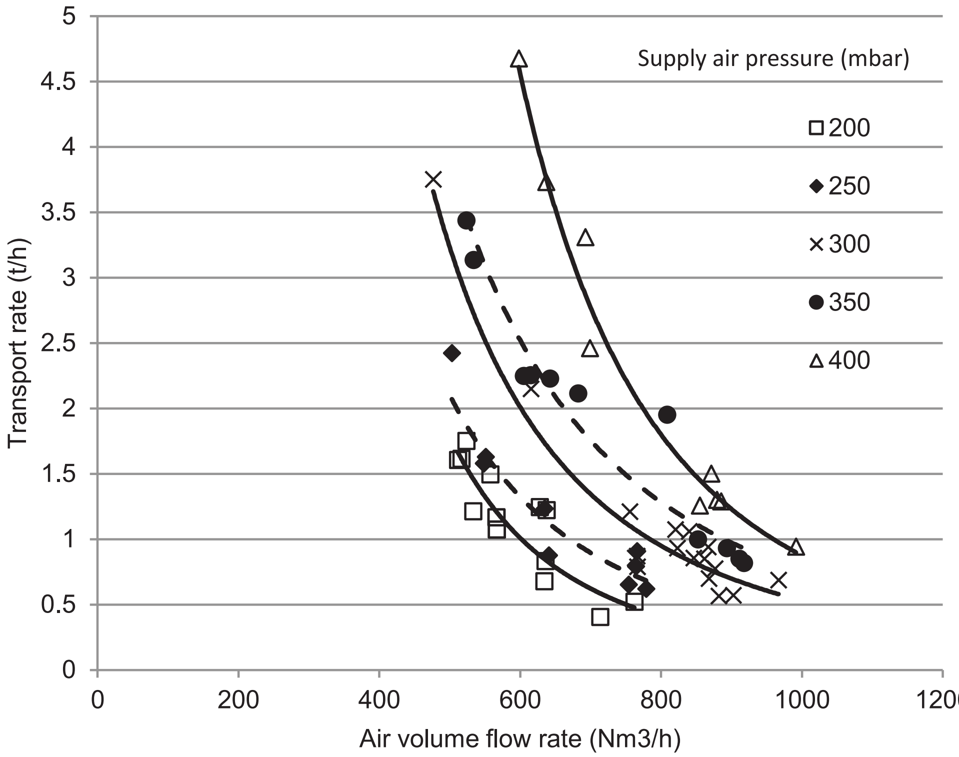

Figure 10: Pneumatic characteristics curves for "fine" wheat flour in pilot test rig

As per the test observations and measurements, it is clear that the both products are good candidates for "medium phase" conveying. During the trials of higher loading ratios (with high feeding rate and low air volume flow), the pipeline was blocked. Pneumatic conveying characteristic curves were drawn for both qualities of wheat products for conveying in pilot test rig; one of them for fine quality is shown in Figure 10.

7. CONCLUSION

Two different wheat products; "Fine quality" and "Grove quality" were tested in the pilot scale pneumatic conveying test rig within a wide range of conveying parameters (air supply pressure, air volume flow rate and solids mass flow rate). Both products show good performances under medium phase conveying conditions. The conveying trials with high solids loading ratio (dense phase) were not stable and mostly ended up with pipeline blockages.

The observations made during the tests and tests results were used to formulate a design and simulation calculation software “PneuDesign”. PneuDesign for wheat products based on the pilot tests that can be used to design an industrial scale conveying system completely new and/or simulate and optimise an existing conveying plant, to increase solids transport rate and minimise energy consumption by optimising compressed air consumption.

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