A New Design Approach for of Pneumatic Conveying

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ABSTRACT

It has been shown that a simple model for pressure drop calculation based on classical Darcy’s equation with some modifications can be used for pneumatic conveying. The predicted pressure values match with the test data reasonably well.

INTRODUCTION

It has been reported that on offshore drilling rigs the abrasion rate in the bulk handling pipe system could be as high as 0.6 mm per transferred 1000 ton of weight material[1]. Leaks in the bulk handling system leads to discharges of bulk material to the atmosphere and significant dusting problems with associated difficulties to satisfy occupational hygiene requirements on the rigs. Hence, it is of utmost importance that the bulk material handling system for the offshore industry is designed with great care. The major challenge facing the designers of pneumatic transportation systems has been always to reliably scale up based on the results from pilot scale test facilities.

It is difficult to relate the rheological properties of bulk material in a pneumatic conveying system to applicable common quantities like the viscosity of the mixture. In this paper the rheological properties has been built into a pressure drop coefficient concept. A simple model[2] for prediction of pressure drop in pneumatic conveying systems has been used for calculating pressure drops in both horizontal and vertical pipe sections. A pressure drop coefficient (K) has been introduced, which has been shown to be independent of the pipe diameter and could be used for both dilute and dense phase pneumatic conveying situations.

LITERATURE SURVEY

Many of the widely used pressure drop calculation techniques[3-7] do not take into account the location and number of bends. In some cases[8] a constant pressure gradient has been considered along straight pipe sections. In most of the calculation techniques available, pressure drop in a straight section has been considered often to comprise of two components, i.e. pressure drop due to air alone and additional pressure drop due to the presence of solids. Further, the pressure drop calculation techniques often require knowledge of the value of the coefficient of friction due to solids and some techniques[9] even use solid velocity values. Determination of solid velocity value would be rather difficult in dense phase pneumatic conveying situations. Even with respect to assessment of the solids friction factor, divergent opinions can be found in the literature[9-11].

TEST SET-UP

During the testing, three different test loops were used. The three test loops with pipe diameters 80 mm, 100 mm and 125 mm were 70 m, 66 m and 68 m long respectively and had no vertical section. A schematic pipe layout with 80 mm, 100 mm and 125 mm pipelines is presented in Figure 1, which was a closed loop.

Several pressure transmitters were located at different points on the pipeline. The pressure data was recorded using LABVIEW software. The tests were conducted at different start pressures at the blow tank, and an attempt was made to cover a wide range of solids loading ratios during the transportation in order to achieve a wide range of pressure drops during pneumatic transportation.

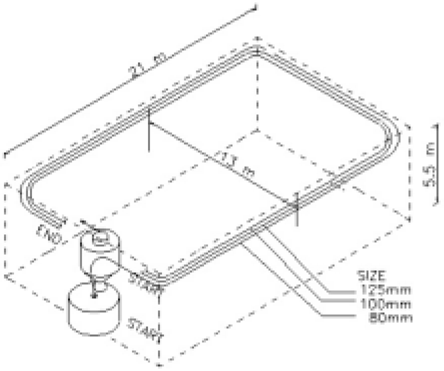

Figure 1. Schematic layout of the pipelines used.

TEST MATERIAL

The three bulk powders used for the test programme were as follows:

Table 1. Data for Test Material

Test Material	Mean Particle Size µm	Density (kg/m^3)
Barite	12	4200
Cement	15.5	3100
Ilmenite	9.5	4600

MODEL FOR PRESSURE DROP CALCULATION

The usual assumption of pressure drop determination in gas-solid two-phase flow has been to consider the total pressure drop comprising of two components, i.e., pressure drop due to the flowing gas alone (ΔP_f) and the additional pressure drop (ΔP_s) due to the presence of solid particles[12,13].

$$\Delta P = \Delta P_f + \Delta P_s \qquad (1)$$

In this article, the Darcy's equation has been used in a slightly modified form[2] for the pressure drop calculation as given below. The air-solid flow has been considered as a mixture having its own flow characteristics.

$$\Delta P = \frac{K \cdot L \cdot \rho_{sus} \cdot v_{entry}{}^2}{2D} \qquad (2)$$

Equation (2) has been used for calculating the pressure drop for straight pipe sections irrespective of whether it is vertical or horizontal. For pressure loss due to bends the equation in a slightly different form has been used, which is similar in form to that used by others[12,13].

$$\Delta P = \frac{K \cdot \rho_{sus} \cdot v_{entry}{}^2}{2} \qquad (3)$$

Using equations (2) and (3), the value of 'K' was calculated for horizontal sections and bends based on pressure drop values from experiments.

TEST RESULTS AND DISCUSSIONS

Tests were carried out with 80 mm, 100 mm and 125 mm diameter pipelines with all the three test bulk materials, i.e. barite, cement and ilmenite. All the pressure data were recorded from the various pressure transducers located on the pipeline at different locations. Using the pressure drop values in the horizontal sections, 'K' values have been calculated for all the tests. The distance between two consecutive transmitters considered for this purpose was never more than 2 m to 3 m. All 'K' values for barite tests with 80 mm pipeline are plotted with respect to the (velocity)^2 for horizontal section and are presented in Figure 2. The velocity here denotes the air velocity at the entry to each test section under consideration.

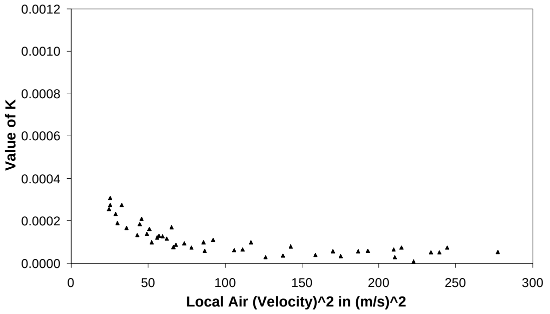

Figure 2. Nature of Variation of ‘K’ for Barite With Change in (Velocity)^2, Pipe diameters 80 mm.

It is clear that the value of ‘K’ decayed exponentially until it reached almost a constant value. Based on the test data with 100 mm pipe and bulk material barite, the variation of ‘K’ with the local (velocity)^2 is presented in Figure 3.

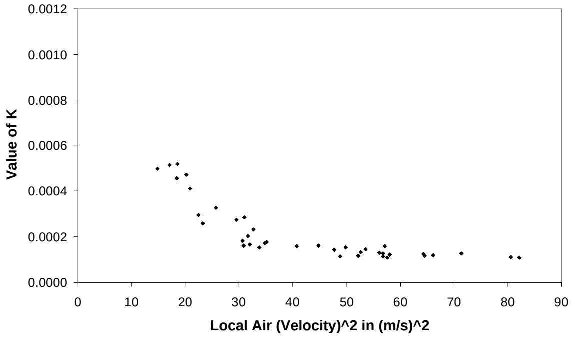

Figure 3. Nature of Variation of ‘K’ for Barite With Change in (Velocity)^2, Pipe diameters 100 mm.

Similar tests were then conducted with barite using 125 mm pipeline also. It was quite interesting to note that all the three graphs for ‘K’ for barite for horizontal section for 80 mm, 100 mm and 125 mm pipelines showed similar trends. A cumulative plot of all the data is presented in Figure 4. Naturally next sets of tests were conducted with cement with 80 mm pipe size in order to ensure that similar nature prevailed for cement also. The nature of variation of ‘K’ for 80 mm pipe for cement has been presented in Figures 5.

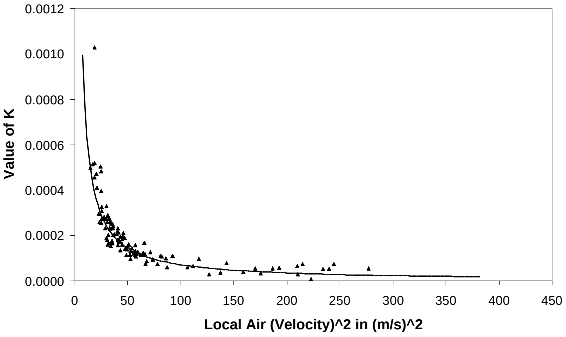

Figure 4. Nature of Variation of ‘K’ for Barite With Change in (Velocity)^2, Pipe diameters 80 mm, 100 mm and 125 mm.

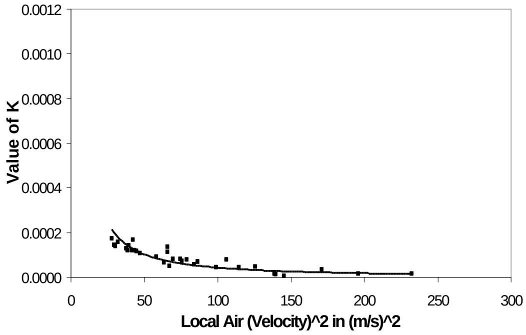

Figure 5. Nature of Variation of ‘K’ for Cement With Change in (Velocity)^2, Pipe diameter 80 mm.

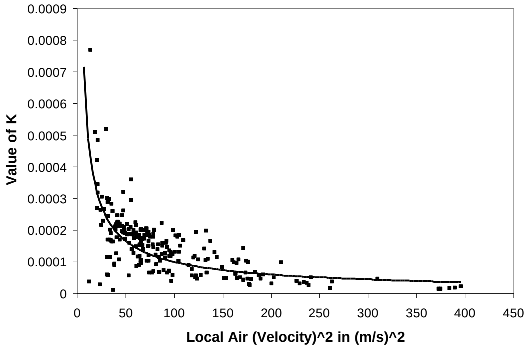

Figure 6. Nature of Variation of ‘K’ for Cement With Change in (Velocity)^2, Pipe diameters 80 mm, 100 mm and 125 mm.

It was noticed that when all the three graphs for ‘K’ for horizontal section for cement for 80 mm, 100 mm and 125 mm pipelines were superimposed on each other they also followed the pattern as observed for barite and the same has been presented in Figure 6.

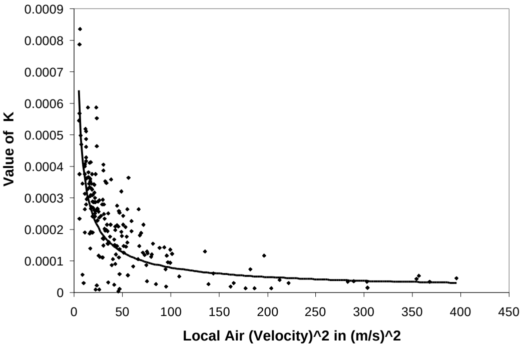

Figure 7. Nature of Variation of ‘K’ for Ilmenite for horizontal section With Change in $(\text{Velocity})^2$, Pipe diameters 80 mm, 100 mm and 125 mm.

Figure 7 depicts the variation of ‘K’ for horizintal section for ilmenite for pipe diameters 80 mm, 100 mm and 125 mm all together.

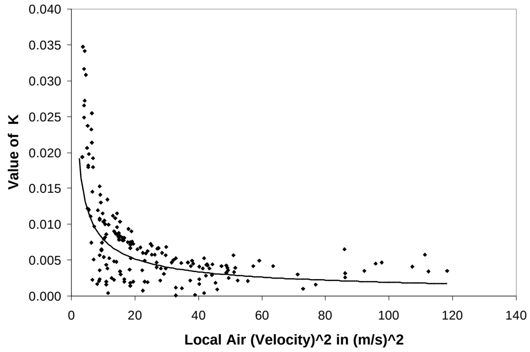

Figure 8. Nature of Variation of ‘K’ for 5D bend for Ilmenite With Change in $(\text{Velocity})^2$, Pipe diameters 80 mm, 100 mm and 125 mm.

Similar graphs for ‘K’ values have been obtained for all pipe components including bends, valves etc. which contributes to pressure drop during pneumatic conveying. It was found that all the ‘K’ graphs followed similar trends. As an example the variation of ‘K’ for 5D bend during Ilmenite transportation using all the three pipe sizes has been presented in Figure 8.

VALIDATION

From the tests already done, there was enough data corresponding to a number of pressure transmitters placed along the pipelines at several locations, for each pipe size and bulk material combination. For each pipe size and bulk material combination, several starting pressures at the blow tank and airflow rates were used. With each of these test parameters, pressure drops were calculated in steps of discrete pipe lengths using ‘K’ values already obtained and calculated pressure drops along the whole pipe layout for the total length of the pipeline used for the experiments. This procedure generated pressure data at each of the transmitter locations on the pipeline. Consequently, the calculated pressure vs. experimentally recorded pressure data were plotted at each of the transmitter locations.

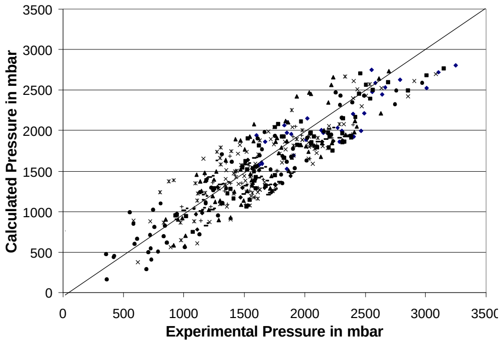

Figure 9. Calculated vs. Experimental Pressure Values at Different Locations on Pipeline; Bulk Material-Barite, Pipe Diameter 80 mm.

Figure 9 shows the calculated pressure values vs. the predicted pressure values for barite in 80 mm pipeline at various locations on the pipeline. Figure 10 depicts the calculated pressure values vs. the predicted pressure values for cement in 80 mm pipeline at various locations on the pipeline.

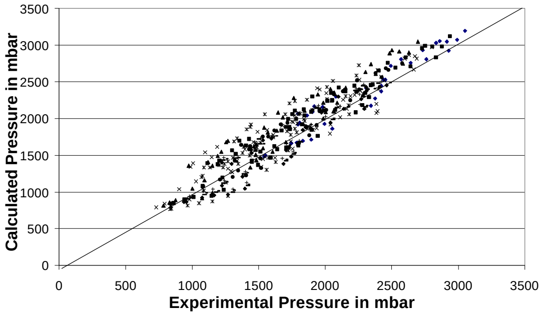

Figure 10. Calculated vs. Experimental Pressure Values at Different Locations on Pipeline; Bulk Material-Cement, Pipe Diameter 80 mm.

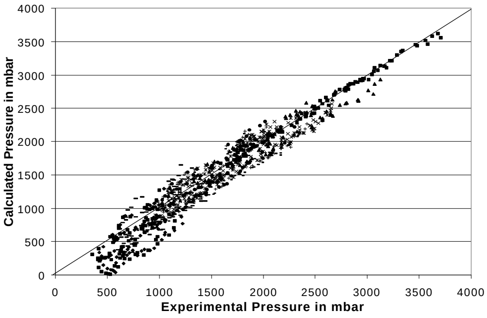

Figure 11. Calculated vs. Experimental Pressure Values at Different Locations on Pipeline; Bulk Material-Ilmenite, Pipe Diameter 80 mm.

Figure 11 shows the variation of predicted pressure vs. calculated pressure for ilmenite transportation in 80 mm pipeline. It is clear from Figures 9-11, that the calculated pressure values are in reasonably good agreement with the experimental pressure data and the predicted values are almost evenly distributed about the central line.

CONCLUSIONS

The scaling up technique proposed in this article is based on a simple model and does not need complicated calculation techniques. This technique, when applied to three different pipe sizes and two different bulk materials, gave reasonably good results. The rheological properties of the mixture are imbedded into a pressure drop coefficient. The unique thing about this technique is that it could be applied to both dense phase and dilute phase pneumatic conveying situations. Hence, this technique promises to be a valuable tool for scaling up in case of both dense phase and dilute phase pneumatic conveying.

LIST OF SYMBOLS

K - Pressure drop coefficient

ΔP- Total pressure drop (mbar).

ΔP_f - Pressure drop due to flowing gas alone (mbar).

ΔP_s- Additional pressure drop due to presence of solids (mbar)

L - Length of pipeline (m)

D - Pipe diameter (m)

ρ_{sus} - Suspension density defined as

$$\frac{Mass\ of\ solids + Mass\ of\ gas}{Volume\ of\ solids + Volume\ of\ gas}\ (\mathrm{kg/m^3})$$

(volume of gas to be calculated at the entry pressure condition at the test section)

v_{entry} True air/gas velocity at the entry to the test section (m/s)

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