MODELLING PIPELINE BLOCKAGE CONDITION FOR PNEUMATIC CONVEYING OF FLY ASH

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Abstract

For the reliable design of pneumatic conveying systems, an accurate estimation of the minimum transport boundary is of significant importance. Based on the experimental data of three different powders conveyed over a range of pipe lengths and diameters, it is found that with increase in pipe diameter, the requirement of minimum conveying air velocity increases. To capture the pipe diameter effect, a Froude number based approach has been introduced to reliably represent the minimum transport boundary. This has shown some promise in that an increase in pipe diameter has not changed the requirement of the minimum Froude number values for two products and has provided only an insignificant change for another product. However, both the minimum air velocity and Froude number requirement are expected to vary quite considerably for other powders and granular products. More efforts are needed to establish a unified criterion to represent minimum transport condition for a wide range of products and pipelines.

1. Introduction

For reliably designing optimal industrial plants, the accurate prediction of the minimum transport or capacity limitation boundary for the dense-phase pneumatic conveying of powders through a given pipeline system is of significant importance. Such information affects the determination of maximum solids loading and the proper sizing of the conveying pipeline. Some fundamental transport boundary models based on powder mechanics have been developed for the low-velocity slug-flow of granular products (Wypych and Yi, 2003). However, the fluidised dense-phase conveying of powders involves far more complex interaction between the particles, carrier gas and pipe/bend wall, and most models to date have been largely empirical (Mills et al., 1982; Mills, 2004; Mills, 2004a) and based on certain product (cement) and pipeline geometry and does not include pipeline diameter scale-up effect. The aim of this paper is to investigate the effect of diameter scale-up on the minimum conveying air velocity requirement for different powders.

2. Experimental

For the purposes of this study, experimental data of fly ash, ESP dust and fly ash and cement mixture were used which were conveyed in fluidised dense-phase mode with pipeline diameter scale-up conditions. Table 1 lists some physical properties and test pipeline conditions (diameter and length) for these powders. Details of the test program are provided in Wypych et al. (2005) and Wypych (1989).

Table 1: Some physical properties of products tested and pipeline conditions

Powder	**d_{50} (μm)**	**ρ_s (kg/m^3)**	**ρ_{bl} (kg/m^3)**	**D (mm)**	**L (m)**
ESP Dust (Wypych et al. 2005)	7	3637	610	69 105	168 168
Fly Ash (Wypych et al. 2005)	30	2300	700	69 105	168 168
Fly ash (89%), cement (11%) w/w (Wypych, 1989)	19 20	2130 3100	700 950	60 105	168 168

3. Representation of minimum transport condition

Figure 1 and 2 shows the pneumatic conveying characteristics (PCC) for ESP dust conveyed in 69 mm I.D. × 168 m and 105 mm I.D. × 168 m pipes, respectively for different solids and air flow rates. C-D and E-F are the respective unstable boundaries. To investigate the effect of pipe diameter on the determination of minimum conveying air velocity, lines corresponding to the minimum air velocity (at the feed point) and the corresponding Froude number lines have been superimposed on the PCC. These constant minimum air velocity and Froude number lines are tangential to the unstable boundaries.

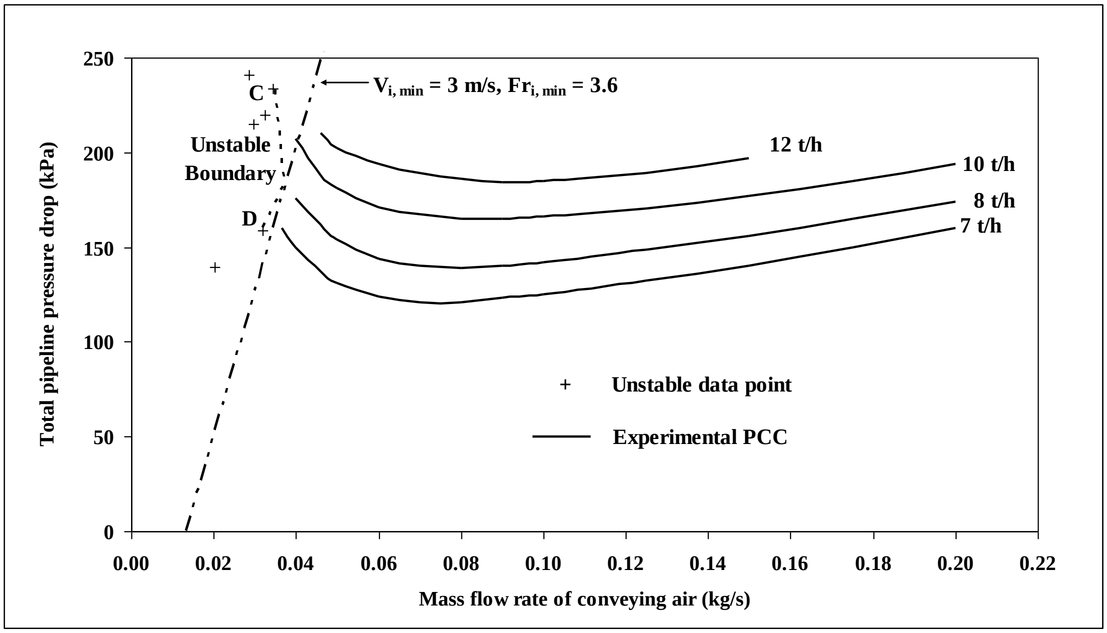

Figure 1: PCC for ESP dust for 69 mm I.D. × 168 m pipe

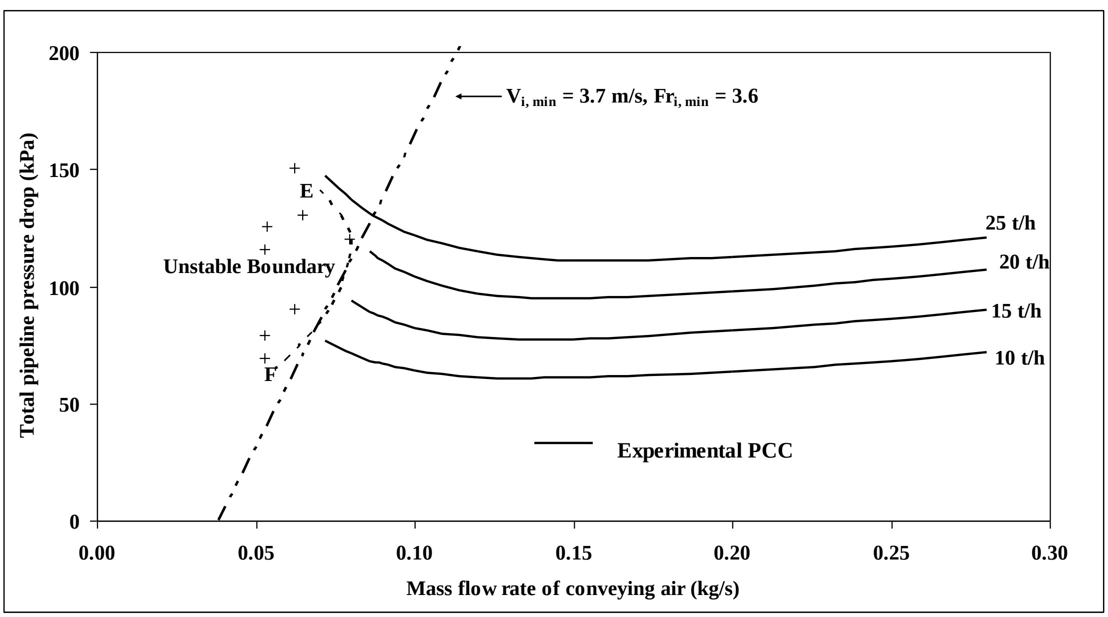

Figure 2: PCC for ESP dust for 105 mm I.D. × 168 m pipe

Figure 1 and Figure 2 shows that with increase in pipe diameter from 69 to 105 mm, the minimum air velocity requirement has increased from 3 to 3.7 m/s, however the corresponding minimum Froude number in both cases are 3.6 (i.e. no change in Froude number for diameter scale-up). Conveying characteristics for fly ash and fly ash-cement mixture are shown in Figures 3 to 6. Constant Froude number lines at the feed point have been superimposed. Values of minimum conveying velocity and the corresponding Froude number for all different products are listed in Table 2.

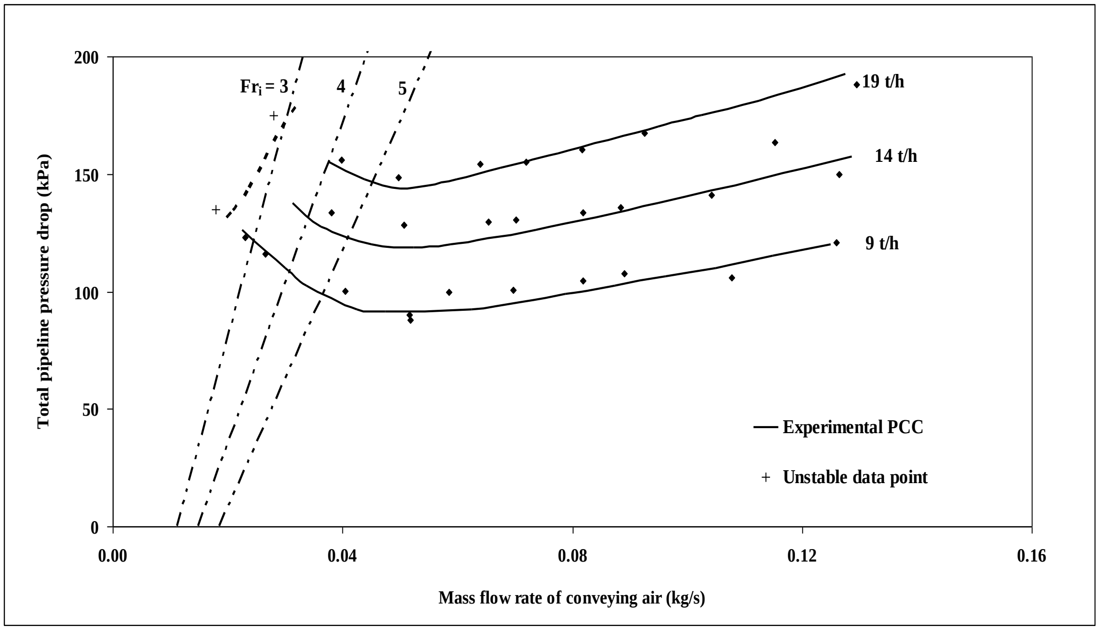

Figure 3: PCC for fly ash for 69 mm I.D. × 168 m pipe

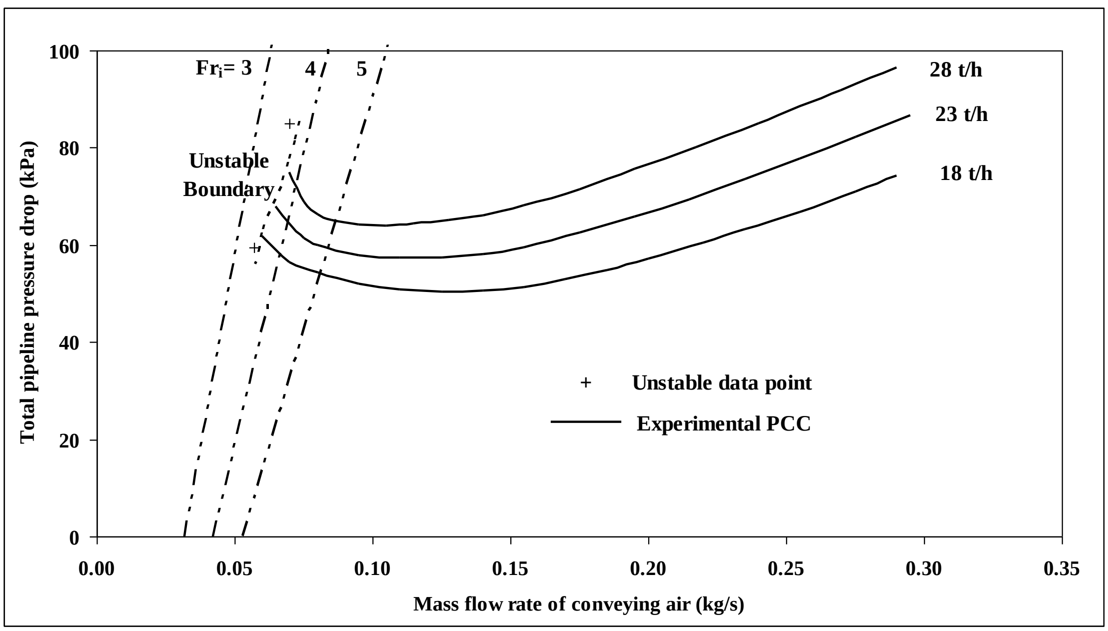

Figure 4: PCC for fly ash for 105 mm I.D. × 168 m pipe

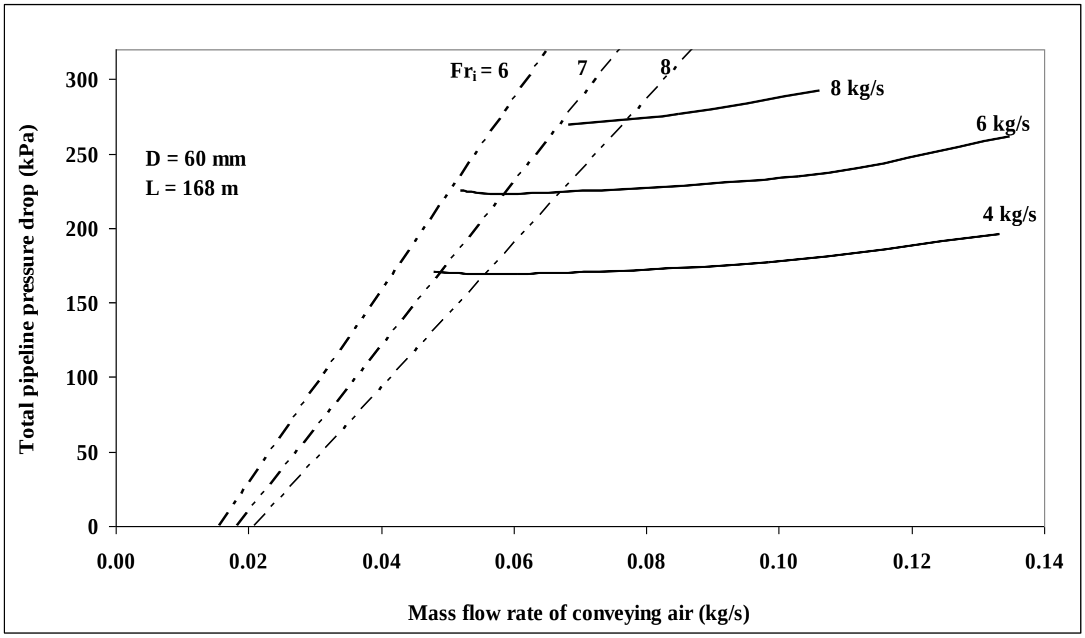

Figure 5: PCC for cement and fly ash mixture for 60 mm I.D. × 168 m test rig (Wypych, 1989)

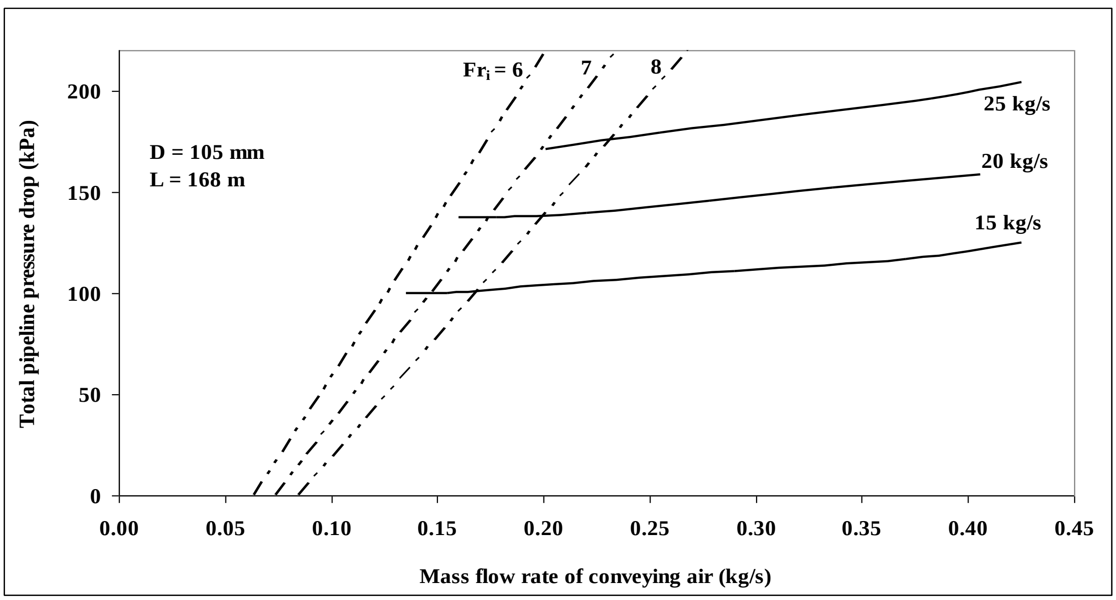

Figure 6: PCC for cement and fly ash mixture for 105 mm I.D. × 168 m test rig (Wypych, 1989)

Table 2: Summary of $Fr_{i, min}$ and $V_{i, min}$ for various products

Powder	**d_{50} (μm)**	**ρ_s (kg/m^3)**	**ρ_{bl} (kg/m^3)**	**D (mm)**	**L (m)**	**$Fr_{i, min}$**	**$V_{i, min}$ (m/s)**
ESP Dust (Wypych et al. 2005)	7	3637	610	69 105	168 168	3.6 3.6	3 3.7
Fly Ash (Wypych et al. 2005)	30	2300	700	69 105	168 168	3.2 3.6	2.6 3.7
Fly ash (89%), cement (11%) w/w (Wypych, 1989)	19 20	2130 3100	700 950	60 105	168 168	7 7	5.4 7.1

Results for fly ash and fly ash and cement mixture (Figure 3 to 6 and table 2) show that similar to the case of ESP dust, the minimum conveying air velocity increases quite considerable with increase in pipe diameter for both the products. Comparatively, the change in the corresponding values of Froude number with diameter scale-up (for the same product) are insignificant (in fact, there is no change for the case of fly ash and cement mixture).

Significance of Froude Number

Traditionally, the Froude Number is a dimensionless parameter measuring the ratio of the inertia force on an element of fluid to the weight of the fluid element (i.e. the inertial force divided by gravitational force), and has been used in open channel flow and wave and surface behaviour calculations in particular. In the context of minimum conveying, the Froude number for a given powder can be considered to represent the inertial (driving) forces needed for a certain gravitational force (or “mixture” weight or solids loading). Other pneumatic conveying researchers also have found Froude number a useful parameter to represent minimum conveying, such as Roski (1987) and Weber (1981).

4. Conclusions

Based on the experimental data of three different powders conveyed over a range of pipe lengths and diameters, it is found that with increase in pipe diameter, the requirement of minimum conveying air velocity increases. A Froude number based approach has been introduced to reliably define the minimum transport boundary for diameter scale-up condition. This has shown some promise in that with increase in pipe diameter for a particular powder has not changed the requirement of minimum Froude number values for two products and insignificant change for another product. Further studies are to be conducted establish a unified criteria to represent minimum transport condition for a wide range of products and pipelines.

List of symbols

d_{50} : Median particle size (μm
D : Internal diameter of pipe (m)
$Fr_{i, min}$: Minimum Froude number at the inlet to the pipe
L : Pipeline length (m)
$V_{i, min}$: Minimum air velocity at the inlet to the pipe (m)
ρ_s : Particle density (kg/m^3)
ρ_{bl} : Loose poured bulk density (kg/m^3)

References

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