

An Investigation into Pneumatic Conveying Characteristics of Carbon Granules in Low Velocity Slug Flow

Chehan L.K.Y. Yapa Mudiyansele¹, Atul Sharma¹, and Michael S.A. Bradley¹

¹ The Wolfson Centre for Bulk Solids Handling Technology, University of Greenwich, UK

Abstract— Low velocity slug flow is an important pneumatic conveying application due to its reduced particle degradation and pipeline wear. This study examines the low-velocity slug flow behaviour of two types of carbon granules (2-3mm and 3-8mm). Data was obtained from 30 conveying trials using an industry-scale pneumatic test rig at the Wolfson Centre in the University of Greenwich.

During the experiments, a transparent pipe section enabled the observation of flow patterns and the estimation of slug velocity through videography analysis. Particle size distribution analysis was conducted after each test run to assess degradation using particle size distribution data of the conveyed material, with samples obtained using a full-stream cross-cut sampler.

The analysis part focused on pressure drop across straight sections and bends, considering superficial air velocity, particle diameter(D50), solid loading ratio, and throughput. Videography-derived slug velocity was compared against predictions from the Legel and Schwedes (1984) equation to evaluate model accuracy. Additionally, the study also examined trends in particle degradation and their impact on pipeline pressure drop. Experimental data was used to evaluate the predictions of existing low-velocity slug flow models developed by Kofu and Ochi (2008), Mi and Wypych (1994), and Pan and Wypych (1997). It was concluded that Kofu and Ochi's model aligns relatively better with experimental data, although none of the models' predictions are sufficiently reliable for real-world applications.

Keywords: low velocity slug flow; pressure drop models;

1. Introduction

Pneumatic conveying can be categorised into two modes: dilute and dense phase. Dense phase conveying uses lower velocities, resulting in reduced particle degradation, less pipeline wear, and lower energy consumption compared to dilute phase. Low Velocity Slug Flow (LVSF), a subcategory of dense phase, is widely used to convey materials[1]. Hence, several researchers have made attempts to develop a reliable model to predict pressure drop and slug velocity in LVSF.

In this study, conveying data were obtained with two types of carbon granules having particle size ranges of 2-3mm and 3-8mm respectively. Conveying data including air mass flow rate, throughput, slug velocity and the pressure drop along the pipeline were analysed. Between each test, particle size distribution was also analysed to evaluate the effect of particle degradation towards the pressure drop and slug velocity. Data obtained from 30 conveying trials were used to evaluate LVSF models developed by Legel and Schwedes (1984) for predicting slug velocity, and pressure drop models developed by Kofu and Ochi (2008), Mi and Wypych (1994), and Pan and Wypych (1997)[2-4]. At the latter part of this study, the obtained data were analysed comparing the correlation coefficients and mean percentage errors.

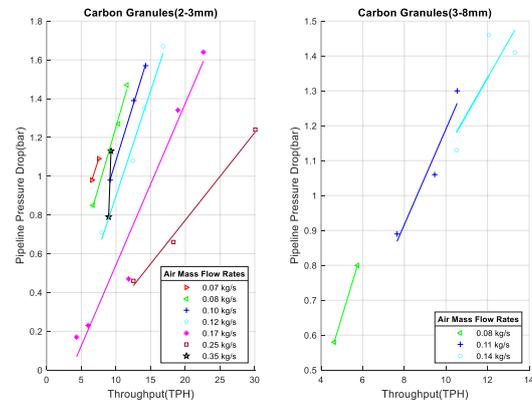


Figure 1. Conveying data of carbon granules 2-3 mm (left) and 3-8 mm (right)

2. Experimental Setup

2.1. Test Rig

The pneumatic conveying test rig consisted of a receiver hopper and a 1.5 m³ blow tank, connected to a 120 m long, 4-inch pipeline containing three long-radius test bends and four straight sections. A transparent pipe section is utilised in the fourth straight section to measure slug velocity through videography analysis. Additionally, the test rig was equipped with a nozzle bank to control the air mass flow rate and 46 pressure transducers distributed throughout the straight sections to measure pressure drop. The solid mass flow rate was adjusted by varying the blow tank air ratio.

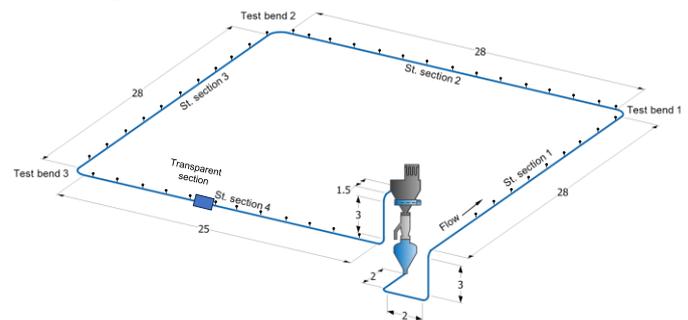


Figure 2. Pneumatic conveying test rig at the Wolfson Centre (all dimensions are in meters)

2.2. Particle Size Analysis

To evaluate particle degradation between trials, carbon granule samples were collected using the full-stream crosscut sampler installed between the receiver hopper and the blow tank. These samples were subsequently subjected to particle size distribution (PSD) analysis.

2.3. Videography analysis

Slug velocity was determined using a 136 cm long transparent pipe section through videography analysis. Videos were recorded at 60 FPS.



Figure 3. Transparent pipe section in the test loop

3. Results and Discussion

Using the data from the conveying trials, the average slug velocity from each trial was initially compared with the slug velocity calculated using the Legel and Schwedes equation. Subsequently, the average pressure drop observed at the fourth straight section during steady-state flow was compared against the pressure drop models by Kofu and Ochi (2008), Mi and Wypych (1994), and Pan and Wypych (1997).

3.1. Results

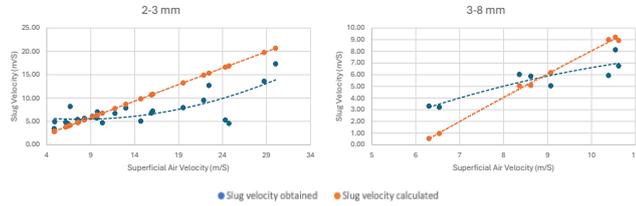


Figure 4. Experimental pipeline pressure drop data compared to predictions from the Legel and Schwedes model

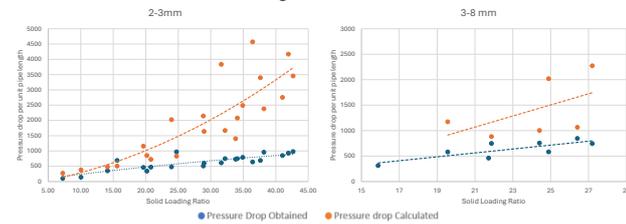


Figure 5. Experimental pipeline pressure drop data compared to predictions from the Mi and Wypych model

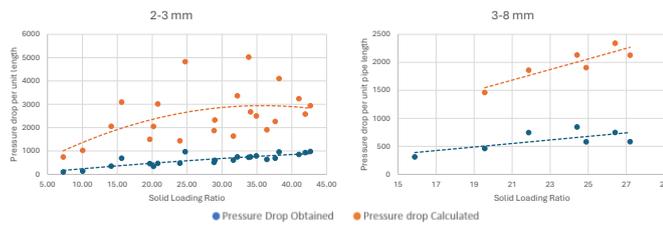


Figure 6. Experimental pipeline pressure drop data compared to predictions from the Pan and Wypych model

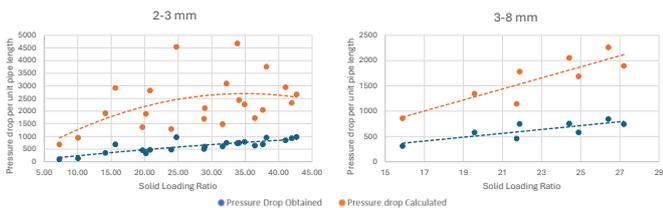


Figure 7. Experimental pipeline pressure drop data compared to predictions from the Kofu and Ochi model

3.2. Discussion

The correlation coefficients and mean percentage errors derived from the experimental data and model predictions are presented in the Table 1.

TABLE I. CORRELATION COEFFICIENTS AND MEAN ERRORS

Comparison	Correlation Coefficient		Mean Percentage Error	
	2-3 mm	3-8 mm	2-3 mm	3-8 mm
Experimental vs predicted pressure drop using Legel and Schwedes equation	+0.71	+0.90	47.9%	37.9%
Experimental vs predicted pressure drop using Mi and Wypych equation	+0.56	-0.32	214%	105%
Experimental vs predicted pressure drop using Pan and Wypych equation	+0.73	+0.82	357%	179%
Experimental vs predicted pressure drop using Kofu and Ochi equation	+0.72	+0.97	321%	160%

The results clearly indicate that the calculations with Legel and Schwedes equation correlate well with the actual slug velocities obtained. Further, the experiments revealed that the equation can accurately predict velocity when the particles are larger.

Regarding the pipeline pressure drop predictions related to LFSF of carbon granules, the Mi and Wypych equation exhibits the lowest correlation coefficients and mean percentage errors, with predictions being more accurate at lower solid loading ratios. It was also noted that the Pan and Wypych equation shows better correlation, but lower accuracy compared to the Mi and Wypych equation. Additionally, both equations failed to provide accurate pressure drop predictions at low solid loading ratios for 3-8mm carbon granules conveying. Consequently, these data points were excluded when calculating the correlations.

Despite the considerable error, the Kofu and Ochi equation with its highest correlation coefficients, emerged as the most reliable among the three equations considered in this study. For smaller particle sizes (i.e., 2-3mm), the pressure drop prediction correlations closely resemble those of the Pan and Wypych equation. However, for larger carbon granule particles, the pressure drop predictions correlates better with the actual data.

None of the pressure drop prediction equations demonstrated both high correlation and low mean percentage error. All predictions exhibited at least a 105% error. However, it was evident that all predictive models showed higher accuracy when dealing with LVSF conveying of larger particles.

4. Conclusion

The main conclusions of this study are as follows:

- I. Legel and Schwedes slug velocity predictions are in a good agreement with the actual data.
- II. The Kofu and Ochi equation exhibits the highest correlation coefficient with the actual pressure drop data.
- III. The Mi and Wypych equation has the lowest correlation coefficient but also the lowest mean percentage error.
- IV. None of the predictive models in this study are not adequately reliable. But they can be used to predict the behaviour when the material properties such particle diameter, internal friction coefficient and wall friction coefficient are altered.

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