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VALIDATION OF PARTICLE FLOW THROUGH A CONVEYOR TRANSFER HOOD VIA PARTICLE VELOCITY ANALYSIS

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Abstract

A critical factor in the design of conveyor transfers is the ability for material to flow at a velocity as close to that of the conveyor belt as possible. If particle velocity increases too much issues such as particle attrition, dust generation, chute wear and excessive noise can arise, whereas if particle velocity were to decrease, stagnation zones could develop, resulting in issues such as spillage or chute blockage. There are numerous methods available in which to analyse particle flow through a conveyor transfer, including; continuum based analytical methods, the discrete element method (DEM) and experimental analysis. This paper will detail the validation process for these three methods. The experimental investigations were performed on the conveyor transfer research facility located at the University of Wollongong, using high-speed video to capture the flow and analysis via Image Pro Plus. A continuum based analytical analysis was then used as an additional comparison and validation tool for the experimental results. Lastly, the use of DEM provided a third means of quantification and prediction of the particle velocity through the transfer hood.

1. INTRODUCTION

DEM is becoming increasingly popular in the analysis and visualisation of material flow through conveyor transfer points. DEM validation is not novel as Gröger and Katterfeld [1] have previously simulated material flow at transfer stations and verified the results experimentally. Gröger and Katterfeld [1] primarily investigated the forces generated at an impact plate and the mass flow rates through the transfer station, however DEM validation of the particle velocity through a conveyor transfer is novel.

In the past, the design of conveyor transfers has often relied on trial and error to achieve the desired outcome. The development of continuum based chute flow models, such as that of Roberts [2], has helped to better understand the flow behaviour of bulk materials. With the addition of DEM comes the reality that expensive test chutes may no longer need to be constructed to test various designs, with the design process occurring solely on computer workstations. At present there is still some hesitance to rely on DEM alone as it is still considered to be in its infancy with much more validation required before designers put their full trust in it.

The presented research examines the chute flow model of Roberts [2] and DEM simulations which are compared to the results from a corresponding experimental test facility.

2. CONVEYOR TRANSFER RESEARCH FACILITY

The experimental component of this research is performed on the conveyor transfer research facility, consisting of three Aerobelt^{TM} conveyors arranged to allow steady-state flow of material, as shown in Figure 1. The feed bin supplies material to the first conveyor, inclined at 5º, while the other two conveyors are inclined at 23º. The conveyor transfer being investigated consists of a hood and spoon which is located directly after the first conveyor, however the focus here will only be on the transfer hood detailed in Figure 2. The hood is lined with 6 mm Polystone Ultra to minimise chute wear and frictional losses. From the horizontal ($\theta_e = 0^\circ$), 5° increments have been marked around the hood, indicating the locations where the velocity analysis will be performed. This allows for accurate determination of the point of impact of the trajectory stream, θ_0, coming from the feed conveyor. Polyethylene pellets have been selected as the test material, due to their granular sphero-cylindrical shape as well as robustness. Some particle and wall characteristics are listed in Table 1.

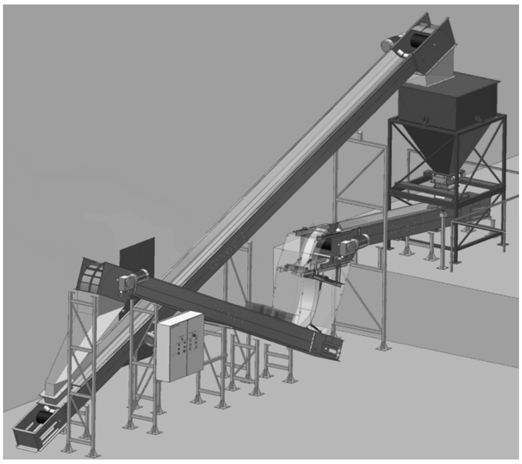


Figure 1 Conveyor transfer research facility

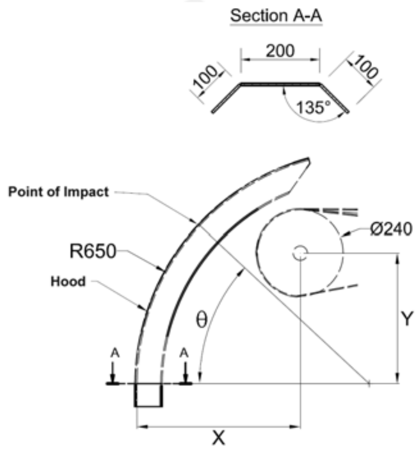


Figure 2 Detail of conveyor transfer hood

Table 1 Particle properties for polyethylene pellets

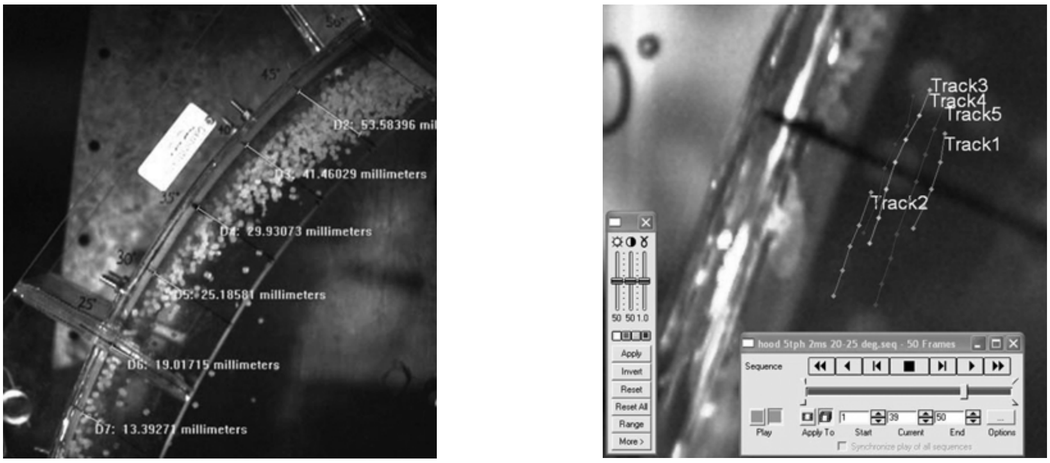
Loose-poured bulk density	515 kg/m^3	
Particle density	919 kg/m^3	
Particle size distribution (2.36 – 3.35 mm)	2.90%	
Particle size distribution (3.35 – 4.00 mm)	11.73%	
Particle size distribution (4.00 – 4.75 mm)	85.37%	
Particle sphericity, ψ	0.873	**tan ϕ_w**
Wall friction angle (6mm acrylic)	19.1 °	0.346
Wall friction angle (Polystone Ultra)	15.75 °	0.282
Wall friction angle (Polyethylene sheet)	12.5 °	0.222
Coefficient of restitution (average)	0.65	

The particle friction is also required for the DEM simulations, however there was some conjecture over the best method to use. The standard instantaneous yield loci test (IYL) was deemed unsuitable due to the material forming a non-consolidated stream when fed onto the conveyor. Ideally the particle friction would be measured by shearing two pellets against each other under various loads, however there was no readily available test equipment to allow this. The decision was made to perform a wall yield loci test (WYL) on the polyethylene pellets by also using a sheet of polyethylene as the wall material to obtain an estimate.

2.1 Experimental Analysis of Particle Flow

One of the features of the conveyor transfer research facility is that the transfer enclosure and hood and spoon have been constructed of acrylic giving the ability to record with a high speed video camera a variety of characteristics of the material flow to analysis the particle velocity. A Redlake X3 MotionPro high-speed video camera has been used to capture the particle flow through the hood at 1000 frames per second. The particle velocity is determined using the software package

Image Pro Plus. Using the manual tracking feature, as shown in Figure 3, particles are tracked by selecting the particle centroid at each time step around the top continuum at each five degree increment. The experimental velocity analysis for a belt speed of 2 m/s and two material feed rates is presented in Table 2, showing the maximum, minimum and average particle velocities as well as the number of particles analysed for each angular increment, N. No data was obtained for the 5º angular position due to the conveyor transfer framework obscuring access.



(a) (b)

Figure 3 (a) Material stream flowing through hood,
(b) manual particle tracking with Image Pro Plus

Table 2 Experimental velocity analysis for a belt speed of 2 m/s

Belt Speed = 2 m/s								
Q_m (tph)	5				28			
θ_0 (º)	47				55			
θ (º)	V_{av} (m/s)	V_{min} (m/s)	V_{max} (m/s)	N	V_{av} (m/s)	V_{min} (m/s)	V_{max} (m/s)	N
45	2.2	1.66	2.66	14	2.31	1.99	2.63	23
40	2.25	1.78	2.72	20	2.32	1.76	2.86	32
35	2.4	2.15	2.9	8	2.27	1.92	3.1	19
30	2.46	1.72	2.89	10	2.42	2.02	3.2	35
25	2.51	2.15	2.75	10	2.53	2.13	2.97	11
20	2.71	2.09	3.51	26	2.55	2.11	3.13	23
15	2.73	2.17	3.14	21	2.55	2.13	3.17	21
10	2.77	2	3.48	31	2.7	2.25	3.14	18
5	-	-	-	-	-	-	-	-
0	3.09	2.55	3.83	29	2.95	2.55	3.29	16

3. CONTINUUM BASED CHUTE FLOW ANALYSIS

The continuum based chute flow analysis by Roberts [2] is applied to the transfer hood, the force diagram is presented in Figure 4. This method is based on averaged conditions and is best suited to thin-stream rapid-flow conditions.

An equivalent friction, μ_e, is determined, which incorporates the particle wall friction, the stream cross-section and the internal shear of the bulk solid, see equation (1), and is assumed to be an averaged constant. The particle velocity at any given angular position through the hood is then found using equation (2) by first determining the constant of integration, K, by solving for the initial conditions, $v = v_0$ and $\theta = \theta_0$.

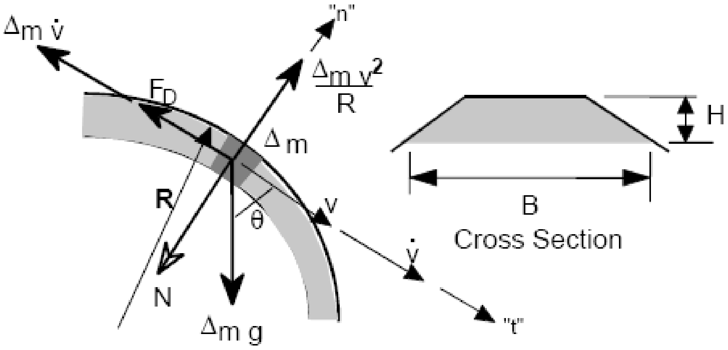


Figure 4 Force diagram for the inverted curved chute [2]

$$\mu_E = \mu_w \left[1 + \frac{K_v v_0 H_0}{vB} \right] \tag{1}$$

$$v = \sqrt{\frac{2gR}{4\mu_E^2 + 1} \left[\left(2\mu_E^2 - 1 \right) \sin\theta + 3\mu_E \cos\theta \right] + Ke^{2\mu_E \theta}} \tag{2}$$

An initial velocity, v_0=2.15 m/s, was assumed at the point of impact on the hood and two analyses were performed. The first set, where μ_E=0.303, was determined using the particle properties from Table 1 and experimentally measured values. K_v is generally a value between 0.4 and 0.6, however has not been calculated as there were no means of doing so. An estimate of 0.4 has been used based on the height of the material stream being substantially smaller than the width of the stream and as such the ratio of pressures will be smaller. H_o is measured as shown in Figure 3a. The second set, where μ_E=0.551, was determined by adjusting the coefficient of wall friction until the particle exit velocity matched that of the experimental analysis. This would require a coefficient of wall friction of 0.51 for the Polystone Ultra, equivalent to a wall friction angle of 27°.

4. DEM SIMULATION OF PARTICLE FLOW

Five DEM simulations were performed using the Chute Maven software, as shown in Table 3. The simulations were conducted at a belt speed of 2 m/s with a mass flow rate of 5 tph. Variations to both the coefficient of particle friction and the coefficient of wall friction have been made to provide a brief sensitivity analysis. Test 2 and test 3 vary only by coefficient of particle friction and it can be observed in Figure 5 that there is negligible difference between the particle velocities through the transfer hood. Test 2 is representative of the experimental results. Test 4 and test 5 vary only in coefficient of wall friction and as is evident in Figure 5, there is a noticeable variation between the particle velocities obtained from the DEM simulations. The restrain of the particles is defined as 100% for no rotation and 0% for full rotation and determined from observing the high speed video of the material flow through the hood. It was found that the percentage of total particles which fully rotate on the surface of the Polystone Ultra liner depends on the stream thickness. In regions where the stream thickness is large with minimal voidage, the percentage of particles that can rotate is low, typically around 10 percent. However, the number of particles which can fully rotate or roll is even lower due to the compaction of the particles. In regions of low stream thickness, it was observed that approximately 30 percent of particles in that region can roll as there is less constraint on the stream. Assuming all particles are restrained fully, especially for a free flowing material, is not ideal, thus a restraint of 80 percent was selected for the majority of the DEM simulations.

Table 3 DEM simulation parameters

Test	Belt Speed (m/s)	Q_m (tph)	Coefficient of Particle Friction	Coefficient of Wall Friction	% Restrain
1	2	5	0.35	0.282	100
2	2	5	0.222	0.282	80
3	2	5	0.966	0.282	80
4	2	5	0.222	0.35	80
5	2	5	0.222	0.45	80

On completion of a simulation, the x- and y- displacement and particle velocity were exported to Matlab where a program (M-file) was written to analyse the exact velocities of the particles at each angular position around the hood along the boundary between the particles and the Polystone Ultra liner.

5. COMPARISON OF METHODS

The particle velocity data from each of the three methods has been plotted to provide an instant visual comparison, as shown in Figure 5. The experimental averaged particle velocities show some minor variation, however, there is still an overall trend present.

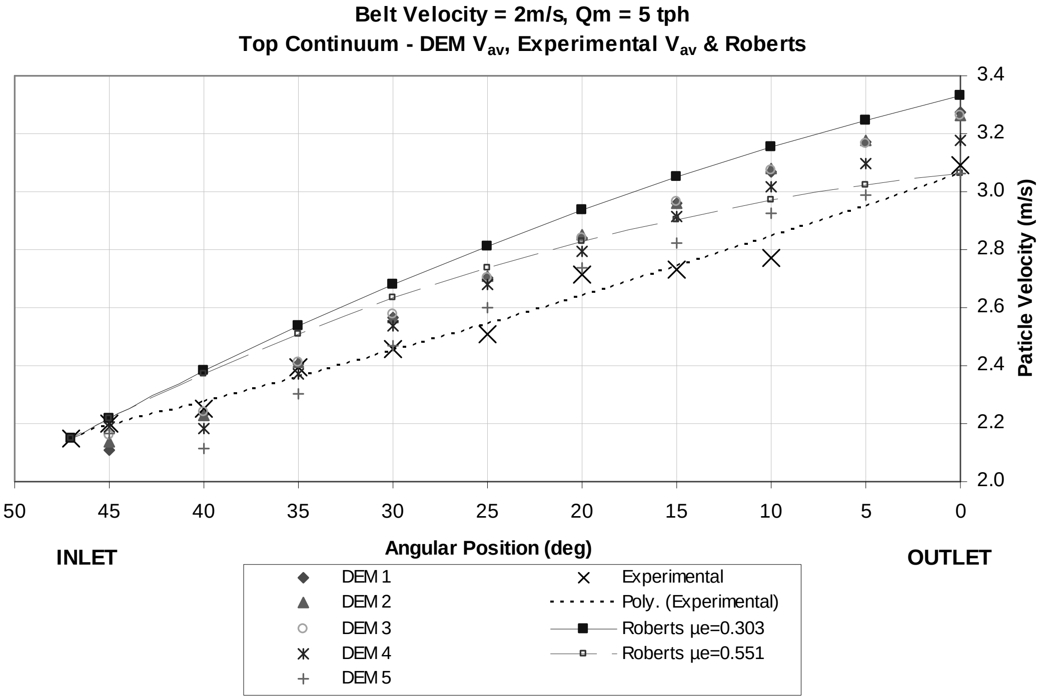


Figure 5 Comparison of particle velocities through the transfer hood

The continuum based chute flow model using the equivalent friction obtained from the particle characteristics, (μ_E=0.303), shows a divergence from the experimental velocities, culminating in an exit velocity 8.8% higher than the experimental equivalent. As an exercise, the equivalent friction was adjusted until the particle exit velocity matched the experimental result, resulting in an equivalent friction of μ_E=0.551, requiring a wall friction angle of 27°, substantially higher than that found experimentally.

The DEM simulation results for the five tests have also been plotted and it can be seen that for the first three tests, there is essentially no difference to the results, indicating that a variation in particle friction has little to no effect. DEM test 2, based on the experimental particle characteristics, showed a 6.7% over-estimation of the exit particle velocity compared to the experimental equivalent.

Test 4 and test 5 have increased coefficients of wall friction to that provided in Table 1 for polyethylene pellets and it is clear that as the coefficient of wall friction increases, the exit particle velocity converges to that of the experimental results to the point that if the coefficient of wall friction continues to rise, the exit particle velocity will under-predict.

6. CONCLUSIONS

Preliminary comparisons have been made of the velocity of material flowing through a conveyor transfer hood with data generated from experimental trials, analytical chute analyses and DEM simulations. These early investigations have shown a slight over prediction of the exit particle velocity from the hood by both the analytical method of Roberts [2] (8.8%) and the Chute Maven DEM software (6.7%). It is hoped that further investigations with other products and transfer geometries/designs will provide more comprehensive trends that can be broadly applied.

A further investigation will be undertaken to verify that the experimental results obtained are not in fact under-predicting, rather than the other methods over-predicting, the velocity of the bulk. This can be achieved by using continuity equations.

The DEM simulations have the potential to reproduce the experimental behaviour of the material flow to a higher degree than the continuum based method due to the bulk flow being simulated. There is also the added advantage that the velocity scatter can be extracted from the data.

The equivalent friction, μ_E, has the largest influence on the predicted velocities for the continuum based chute flow method of Roberts [2]. The larger the value of equivalent friction becomes, the closer the predicted velocity comes to matching that found experimentally. This needs further investigation.

7. NOMENCLATURE

B	width of chute, m
g	gravity, m/s^2
H	stream height, m
H_0	initial stream height, m
K	constant of integration, -
K_v	pressure ration (0.4 – 0.6), -
N	number of particles analysed, -
Q_m	material feed rate, t/hr
R	radius of hood, m
v	particle velocity, m/s
v_0	initial particle velocity, m/s
X	horizontal positioning of hood, m
Y	vertical positioning of hood, m
ϕ_w	wall friction angle, °
θ	angular position around hood, °
θ_e	angle of stream exit, °
θ_0	angle of stream impact, °
μ_E	equivalent friction, -
μ_w	coefficient of wall friction, -

8. REFERENCES

[1] Gröger, T. and Katterfeld, A. *Application of the Discrete Element Method in Materials Handling - Part 3 Transfer Station*. Bulk Solid Handling, Vol. 7, No. 3, 2007, pp. 158 - 166.

[2] Roberts, A. W. *Chute Performance and Design for Rapid Flow Conditions*. Chemical Engineering and Technology, Vol. 26, No. 2, 2003, pp. 163 - 170.

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