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# Evaluation of Belt Conveyor Trajectories

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**ABSTRACT** Since the early 1900s, numerical methods have been used to predict the trajectory of material discharged from a belt conveyor. These methods range from the very basic to complex iterative approaches. Some methods predict similar paths and others vary noticeably, however it is clear that they cannot all be correct. The discrete element method (DEM) is also becoming more widely accepted as a design tool, however, hesitation still exists in some quarters stemming from the lack of experimental validation available. A conveyor transfer research facility has been commissioned at the University of Wollongong to experimentally investigate particle flow mechanisms through a variety of conveyor transfers. As part of this research, preliminary investigations into conveyor trajectories have been undertaken at varying belt speeds and material flow rates using granular polyethylene pellets. This paper presents the trajectory results of an experimental test program and compares these findings with numerous numerical trajectory methods as well as DEM simulations in an attempt to validate the predictive approaches available to generate conveyor trajectories. Early findings suggest the method of Booth provided the most accurate prediction, while the DEM also compares favourably to the experimental results.

## 1. INTRODUCTION

Belt conveyors are used in a multitude of industries to transport material from one location to another. Belt conveyors can be configured in many ways, from a single run which might form a stockpile, to many interconnected belt conveyors, necessitating the use of transfers to successfully deliver material through the system. Whichever method applies, the way in which material leaves the head of a conveyor, will dictate the path the flow of material takes to the next step in the process. Many installations run successfully with systems that have been in operation for many years, however not all have been ‘engineered’, instead relying on a rule-of-thumb approach by experienced and long serving staff.

The research presented in this paper focuses on the material trajectory as it leaves the head pulley of a belt conveyor, from: an experimental perspective; predictions made by applying a variety of numerical trajectory models; and the use of the discrete element method (DEM). Comparisons will be made between these three methods to establish whether the numerical models or the DEM simulations can successfully predict the experimental particle trajectories.

## 2. EXPERIMENTAL

An experimental conveyor transfer research facility was designed and commissioned at the University of Wollongong to allow detailed velocity based particle flow analysis through hood and spoon style conveyor transfers, see Figure 1. The facility consists of three Aerobelt$^{TM}$ conveyors arranged to allow continuous re-circulation of material. The feed bin is approximately 1m$^3$ in volume and supplies material to the first conveyor (L = 4.5 m), inclined at 5º with a smooth belt, while the other two conveyors are inclined at 23º, both having crescent belts (L = 6.7 m and L = 11.4 m). Variable speed drives control the three conveyors independently and a maximum belt speed of 7 ms$^{-1}$ can be achieved. Polyethylene pellets ($\rho_s$ = 919 kg m$^{-3}$, $\rho_b$ = 514 kg m$^{-3}$) were selected as the test material due to their robust nature and uniform particle size.

Several methods were used to produce experimental trajectory profiles with varying success. Preliminary testing utilised the existing acrylic covers but a maximum belt speed of 2.25 ms$^{-1}$ was achievable due to interference by the covers. This method also resulted in parallax error making analysis inaccurate. A second method involved optical laser equipment from Bluescope Research being tested by an undergraduate Mechanical Engineering thesis student [1]. Ultimately limitations with the focal lengths of the lasers meant qualitative results were not obtainable.

**Figure 1** Conveyor transfer research facility

An enhancement of the preliminary trajectory setup was then produced, including the addition of a 100 mm square grid behind the trajectory stream. Also included in this phase of the testing was the addition of an interception hopper, designed to manually slide along the receiving conveyor allowing capture of the trajectory stream and smooth delivery of material onto the receiving conveyor. This trajectory hopper also allowed higher belt speeds to be tested, beyond the limiting 2.25 $ms^{-1}$ of the preliminary trajectory testing, up to and including 7 $ms^{-1}$. All extraneous framework was removed to give the most uninterrupted view of the trajectory possible and the final arrangement can be seen in Figure 2.

**Figure 2** Trajectory for a belt speed of $V_b$ = 4 $ms^{-1}$ and material feed rate of $m_s$ = 37.8 tph

Low material feed rates were tested to generate a thin particle trajectory stream. High material feed rates were also tested, with the edge distance set to maximum for each belt speed tested [2]. Table 1 summarises the range of experimental tests performed. Limitations with the feeding arrangement resulted in a maximum feed rate of 37.8 tph being achieved. This meant that full capacity conveying was not achievable for some of the higher belt speed tests.

**Table 1** Experimental trajectory setup

| **Belt Speed ($ms^{-1}$)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| **Low Feed Rate (tph)** | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 |
| **High Feed Rate (tph)** | 19 | 31 | 37.8 | 37.8 | 37.8 | 37.8 | 37.8 |

Each test performed was videoed in the same way as the preliminary tests. The tests were also photographed, not by capturing the overall trajectory, but as a series of successive small sections to minimise any potential parallax error. These sections were then analysed and the data combined to produce overall trajectories. The results of the experimental trajectory analyses are presented in Figure 3 and 4. No trajectory curve was produced for a belt speed of $V_b$ = 7 ms$^{-1}$ for the low material feed rate due to the stream losing integrity, with the defined boundaries being impossible to detect.

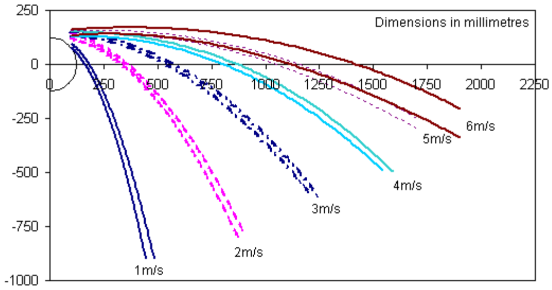


**Figure 3** Experimental trajectories for low material feed rates

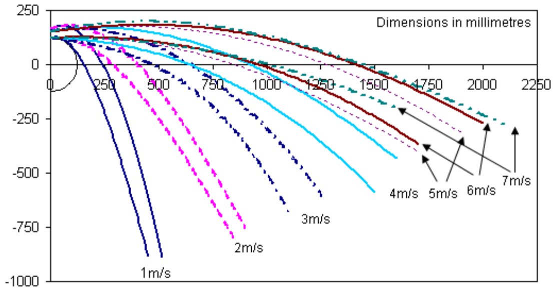


**Figure 4** Experimental trajectories for high material feed rates

For the low material feed rate experiments there was very little difference between the trajectory profiles produced for the $V_b$ = 5 and 6 ms$^{-1}$ tests. A similar observation was seen for the high material feed rate experiments, where the trajectory profiles for the three highest belt speeds (vis. $V_b$ = 5, 6 and 7 ms$^{-1}$) were very similar and in fact overlapped each other. After some investigation, it was found that material slippage was present above $V_b$ = 5 ms$^{-1}$. As a result, the decision was made not to incorporate the experimental trajectory data for $V_b$ = 6 and 7 ms$^{-1}$. The most likely cause of this slippage is the distance between the feed point and discharge being too short for the higher belt speeds, resulting in steady-state conveying not being achieved.

A significant finding from the high-speed experimental testing is that the underside of the trajectory stream does not stay flat after discharge. As product moves along the conveyor through the troughed section, the material is forced into a curved geometry, however once the transition zone is reached, the profile of the material changes. The material profile changes through the transition zone, with the underside of the material changing from a troughed to flat profile, when material reaches the head pulley and discharges. This flattening of the material through the transition zone causes a degree of lateral downward velocity to some of the material which continues after discharge, forming what has been termed ‘wings’. Figure 2 shows an example of these wings. The material present in this region of the trajectory stream is not as densely packed as the main body of the trajectory and as such the influence of air drag effects is more pronounced and particles separate quite freely from the main stream.

## 3. NUMERICAL TRAJECTORY MODELS

Conveyor trajectories have been the subject of predictive models dating back to the early 1900’s and has seen a wide variation in the level of complexity of those that exist. Seven main methods can be found in the literature; C.E.M.A. [2,3,4,5,6], M.H.E.A. [7], Booth [8], Golka et al. [9], Korzen [10], Dunlop [11] and Goodyear [12]. These models have been investigated in detail previously by Hastie and Wypych [13] and Hastie et al. [14] and will not be repeated here. Considering the information provided in Figure 3 and 4, the decision was made to only produce numerical based trajectories up to and including a belt speed of $V_b$ = 5 ms$^{-1}$. The parameters for the experimental geometry as well as the particle characteristics for polyethylene pellets have been applied to the seven trajectory methods. Some minor adjustments have been made to these methods such as the material height at discharge, h, and centroid height, $a_1$, which are used in the C.E.M.A. and M.H.E.A. methods and which have been determined directly from experimental measurements. Representative conveyor profiles for the trajectory models are presented in Figure 5.

It is also important to mention that all of these trajectory methods are two dimensional models and as a result, their position corresponds to the central axis of the conveyor from which they emanate. This has implications when comparisons are to be made and will be explained in Section 5.

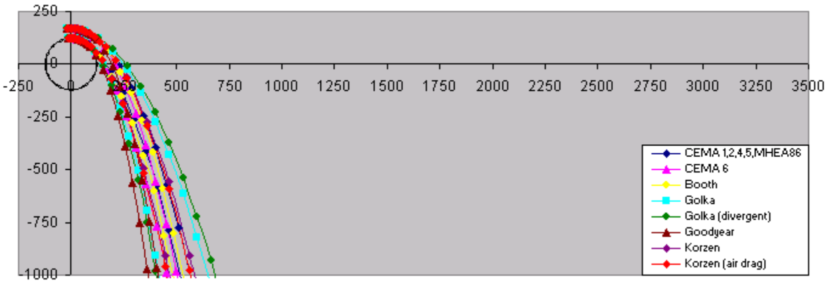


**Figure 5a** Numerically determined conveyor trajectories for $V_b = 1\ ms^{-1}$

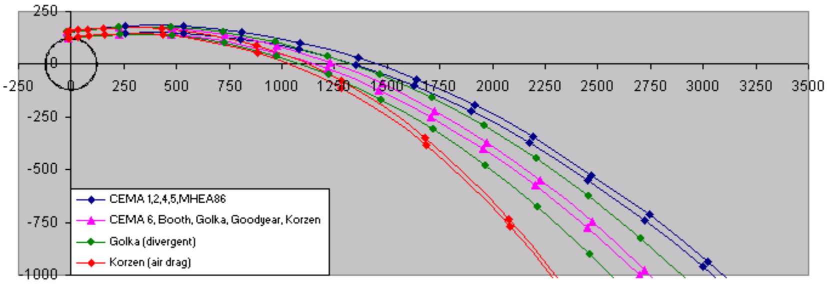


**Figure 5b** Numerically determined conveyor trajectories for $V_b = 5\ ms^{-1}$

## 4. DISCRETE ELEMENT MODELLING

The simulations performed as part of this research have been achieved using the commercial software package, E-DEM, by DEM Solutions. Particles are not just able to be simulated as spheres but as composites of spheres to make up more complex shapes. This has added an extra degree to the trajectory comparisons, allowing investigation of the effect shaped particles have compared to spherical representations. The polyethylene pellets used experimentally have been modelled as spherical particles with a diameter of 4.75 mm and as shaped particles having two spheres of 4.3 mm diameter and merged to have a total length of 4.75 mm.

DEM simulations were performed for the low material feed rate used experimentally, for both spherical and shaped particles. Belt speeds from 1 $ms^{-1}$ to 5 $ms^{-1}$ were simulated. The complete results of these two sets of simulations are shown in Figure 7. It can be seen that there is very little difference, if any, between the results achieved for the spherical and shaped particles. Also, as the belt speed increases, there is a gradual deterioration of the underside of the trajectory stream. This is most evident for the 5 $ms^{-1}$ belt speed simulations.

The high material feed rate trajectories were also simulated as per the data in Table 1, as shown in Figure 8. As a result of the trajectory curves being practically identical for both the spherical and shaped particles, only spherical particles were used to generate simulations for the high material feed rates.

## 5. TRAJECTORY COMPARISONS

Experimentally, it has been shown that 'wings' develop at the lateral extremities of the trajectory stream for the higher material feed rates. Experimental comparisons with the trajectory models could not be achieved directly as the models provide a two dimensional representation of the trajectory stream, hence there is no way to account for the wings. This has lead to the following sets of direct comparisons being made; the experimental upper trajectory boundary being compared with the upper trajectory boundary predicted from the models, experimental trajectories compared with full stream E-DEM simulations and trajectory models compared with E-DEM simulations (thin axial slice only along the centreline).

Figure 6 plots the experimental upper trajectory boundaries for belt speeds ranging from $V_b = 1\ ms^{-1}$ to 5 $ms^{-1}$. Also on this graph are the trajectory model predictions for the corresponding belt speeds. It can be seen that for $V_b = 1\ ms^{-1}$, the experimental trajectory closely follows the Booth method. For belt speeds of $V_b = 2\ ms^{-1}$, 3 $ms^{-1}$, 4 $ms^{-1}$ and 5$ms^{-1}$ the experimental trajectory follows the trajectory model grouping of CEMA 6, Goodyear, Korzen (no air drag), Golka (no divergent coefficients) and Booth. There are some minor variations between these curves which is most likely due to the analysis method used in the experimental testing.

The E-DEM trajectories all showed the 'wings' which were evident in the experimental testing, however are not obvious in the two dimensional representations. This indicates the simulations were able to reproduce the dynamics of the material flow well, mimicking that occurring in reality. Figure 7 and 8 provide comparison graphs of the experimentally generated trajectories and the corresponding E-DEM simulations. As is clear in Figure 7, the experimental curves fit almost identically for all five belt speeds investigated. Figure 8 shows the results for the high material feed rates, however there is some variation present for all belt speeds.

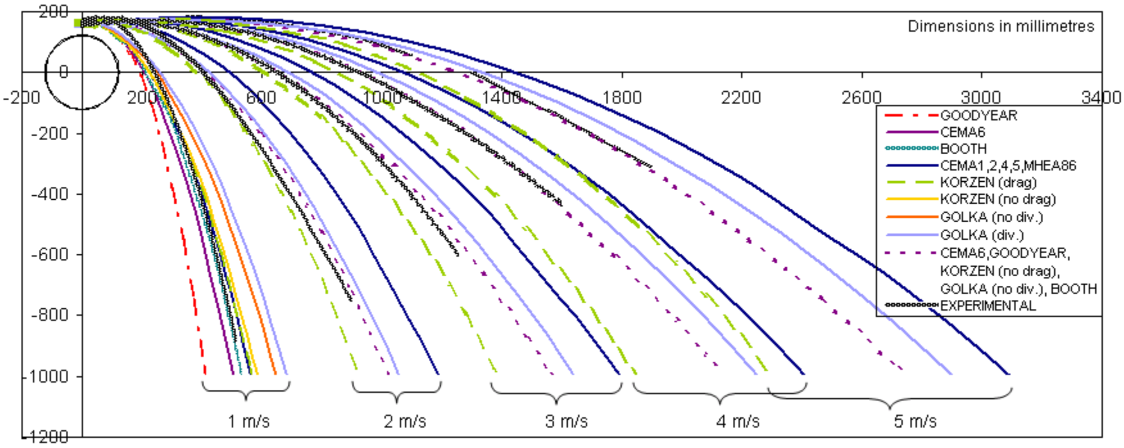


**Figure 6** Upper trajectory boundary comparisons between the experimental tests and trajectory models

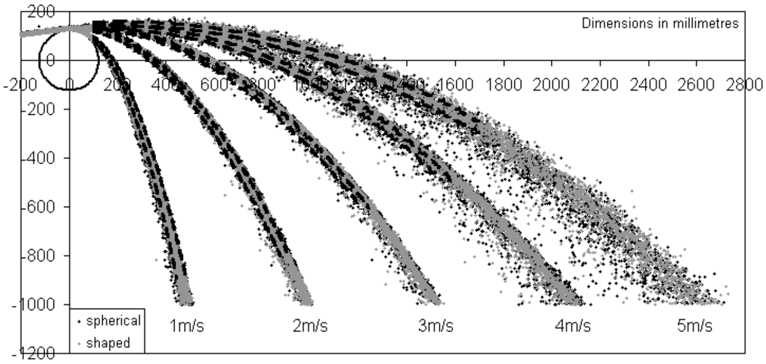


**Figure 7** Low material feed rate experimental trajectories super-imposed over the low material feed rate E-DEM trajectories for spherical and shaped particles

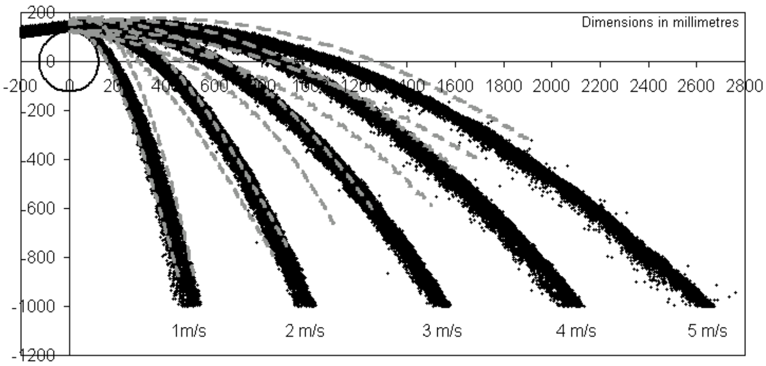


**Figure 8** High material feed rate experimental trajectories super-imposed over the high material feed rate E-DEM trajectories for spherical particles

E-DEM produces three dimensional outputs which does not allow direct comparison with the two dimensional trajectory models. To remedy this, during post processing, there is a function to select regions of interest within the particle data (called binning). A 40 mm slice was taken along the length of the conveyor and down the centre of the trajectory stream which was then extracted for comparison with the trajectory models. Figure 9 shows the results for the low-speed conveying condition, $V_b$ = 1 ms$^{-1}$ with an inset image showing a close up of the bottom of the stream. The Booth method shows the best agreement with the simulation data although the stream is slightly wider. Figure 10 displays the results for a belt speed of 4 ms$^{-1}$. Now, several trajectory model curves predict the same path and have been merged into one common curve. For this comparison, the simulation data fits extremely well with the trajectory models of CEMA 6, Goodyear, Korzen (no air drag), Golka (no divergent coefficients) and Booth. Not shown, are the results for $V_b$ = 2 ms$^{-1}$ and $V_b$ = 3 ms$^{-1}$, but the results showed a similar trend as in Figure 10. On completion of this set of simulations it was found that there were issues with the coefficient of rolling friction used in the simulations, which resulted in the simulations for a belt speed of 5ms$^{-1}$ not being able to achieve the correct particle discharge velocity of 5 ms$^{-1}$. This means that the trajectory produced does not match with the model predictions and has been omitted from the comparisons.

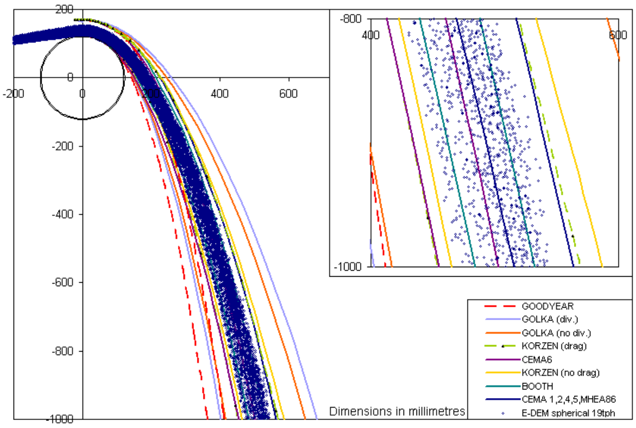


**Figure 9** Comparison of the high material feed rate E-DEM trajectories (with binning used) superimposed over the trajectory models for a belt speed of 1 ms$^{-1}$

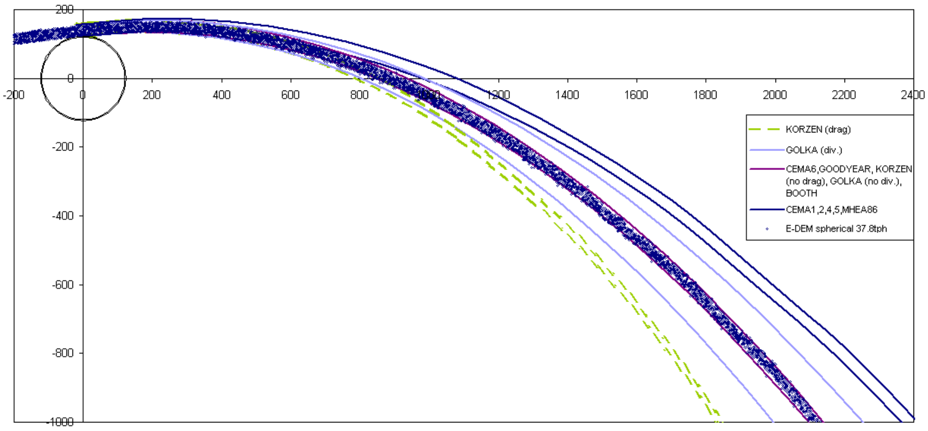


**Figure 10** Comparison of the high material feed rate E-DEM trajectories (with binning used) superimposed over the trajectory models for a belt speed of 4 ms$^{-1}$

## 6. CONCLUSION

Findings of the experimental test program showed that material slip can be an issue when predicting conveyor trajectories, especially for high belt speeds. If material is fed onto a conveyor too close to the discharge point, there is a possibility that the material will not have achieved steady state at discharge, thus may not be leaving at the same velocity as the belt. The comparisons of experimental vs. trajectory models and trajectory models compared with E-DEM simulations have all shown a very close agreement with the Booth method for the range of belt speeds investigated. Comparisons between the experimental results and E-DEM simulations have shown a very good agreement for the low material feed rates but there is some minor variation when considering the high material feed rates. The influence of particle shape in the E-DEM simulations does not appear to have much of an effect on the final trajectory. The effect of rolling friction will also be investigated further. This could be a product specific finding and will need to be investigated further when simulating other materials. Further experimental investigations are planned to generate a database of information allowing more detailed comparisons to be completed.

## 7. ACKNOWLEDGEMENTS

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