Experimental Evaluation of the OLDS Elevator Concept

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Abstract

The OLDS elevator is an Australian designed variant of a screw conveyor in which the screw flight remains stationary and the casing rotates. This device potentially offers several advantages over a screw elevator such as a very linear relationship between rotational speed and throughput which appears to provide flow for any non zero revolution speed. This paper presents data collected in a small scale version of the OLDS elevator operating both vertical and on an incline. A specific focus of this study indicates that the OLDS elevator concept may be a very useful device when operating at an incline to feed filter cake type material into exhaust gas streams for drying.

1 Introduction

Figure 1 diagrammatically shows the OLDS elevator layout as used for the research work in this paper. What differentiates the OLDS elevator from a conventional screw elevator is a fixed screw with a rotating shroud. Operationally the friction of the tubes inner surface rotates/drags the bulk material around the screw helix causing elevation of the product. This simple inversion of the screw elevator concept results is quite different performance characteristics. Among the claims for the OLDS elevator are a reduction in particle attrition, proportional increase in feed rate with tube speed, and a smooth discharge compared to a conventional screw elevator.

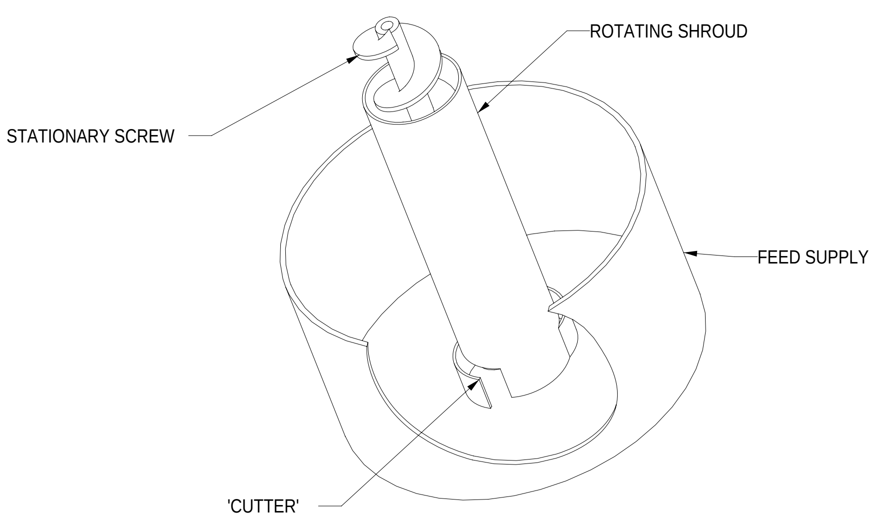

Figure 1 – OLDS elevator illustration

The most significant difference between the research model and commercial units are the elevation heights with the commercial units offering a much greater elevation.

The research experiments conducted for this paper were designed to provide base line data for vertical conveying of a granular material exploring effects of tip clearance and rotational speed for two granular materials. This was expanded to investigate the effect of inclined conveying for which a specific application was envisaged, which is the feeding of filter cake materials into an exhaust gas stream for drying.

2 Filter Cake Feeding

A common method for the drying of fine products at processing plants containing their own power generation plants is to feed dewatered material (filter cake) into a vertical column carrying the power station exhaust gas stream. The residual heat in the gas stream drives the remaining water from the cake leaving dry product at the collection point. In this system several conditions are required for optimal operation. The product needs to be delivered at an even flow rate and clumps are to be avoided. Also, exhaust gas flow out of the material feed system needs to be considered and negated.

A recent industrial project highlighted these difficulties in the feed control system for presenting filter cake into the exhaust gas stream from the power generation plant. In this specific case, the filter cake was delivered to a hopper with a horizontal screw feeder intended to discharge the material into the gas stream in a steady stream. Level control systems were required to maintain a minimum bed depth in the hopper to prevent/limit the blow back of exhaust gas into the process room. This bulk material in question exhibited poor characteristics for screw conveying having high wall friction, low internal friction and moderate levels of cohesion. These material properties generated some difficulties with the discharge and presented clumped material into the stream resulting in gas management difficulties. Compounding issues included high power consumption, low transport efficiency and a correspondingly high axial thrust.

The seemingly unique performance characteristics of the OLDS elevator may provide a future solution to this type of difficulty, our belief is that this elevator will cause much less compaction in the transported material resulting in lower clump formation. The inherent inability of the OLDS elevator to fully clear should form a suitable gas seal and remove the absolute reliance on level controls to minimize the risk of gas escape. At this stage the filter cake described above has not been tested.

3 Experimental Rig

A program of experimental work was undertaken at Newcastle's TUNRA bulk materials handling laboratories. The experimental rig used ZCORP rapid prototyped flights with outer diameter of 38, 42 and 46mm, a core diameter and pitch of 13 mm of 38 mm respectively. In the case of vertical conveying tests four casings of the same outer diameter with different height cutter were tested. The casings' cutters were selected to provide effectively an equivalent volumetric efficiency of 85%, 65%, 45% and 25%. These efficiencies are defined by the theoretical maximum volume of the screw flight per revolution divided by the swept volume of the cutters. The discharge from the experimental rig was directed to a data logging weigh station to determine irregularities in the discharge flow rate.

Additionally we explored a range of rotational speeds from 5 to 40 rad/s and inclinations from vertical to 45^0 degrees.

The bulk materials chosen for this research were Sorghum and Wheat as they cover a range of complex geometries, have a well defined particle size range, and damaged Sorghum particles are very clearly identifiable. The selection of these materials was in part dictated by a desire to utilize discrete element modeling techniques to extend the value of the research. The results of initial DEM simulations can be seen in McBride and Cleary [2].

Two typical Sorghum particles are shown in Figure 2a and are characterized by a slightly elliptical plan shape, with a long dimension of 4.5 mm and a transverse dimension of 3.5 mm (average of 12 grains). The grains are, on average, 2.5 mm thick. A transverse sectional view through the thickness of an individual grains shows a rectangular profile with generously rounded edges. Wheat particles are shown in Figure 2b, have a much larger aspect ratio with a particle length of 6 mm. A transverse section through the Wheat shows an approximately circular profile of 2.5 mm diameter with a small flattened (indented) section approximately 0.3 mm deep along the grains length. All listed grain dimensions have a typical variance of 0.5 mm. The solid density of sorghum is 1366 kg/m^3 and wheat is 1460 kg/m^3 as measured in an air comparison pycnometer.

Figure 2 – Plan photo of the grains used in the experiments; a) sorghum and b) wheat.

Table 1 – OLDS Elevator Principle Geometry and Operational Parameters

Screw diameter (mm)	38, 42, 46
Screw Pitch (mm)	38
Core Diameter (mm)	13
Outer casing, inner diameter (mm)	46.5
Outer casing outer diameter (mm)	50
Height of cutters (mm)	30, 22.5, 15, 7.5
Rotational Speed range	50 – 300 rpm
Elevation angle	45 – 90 degrees
Cutter capture volume / rev normalized against flight capacity. (nominal)	0.2 – 0.9

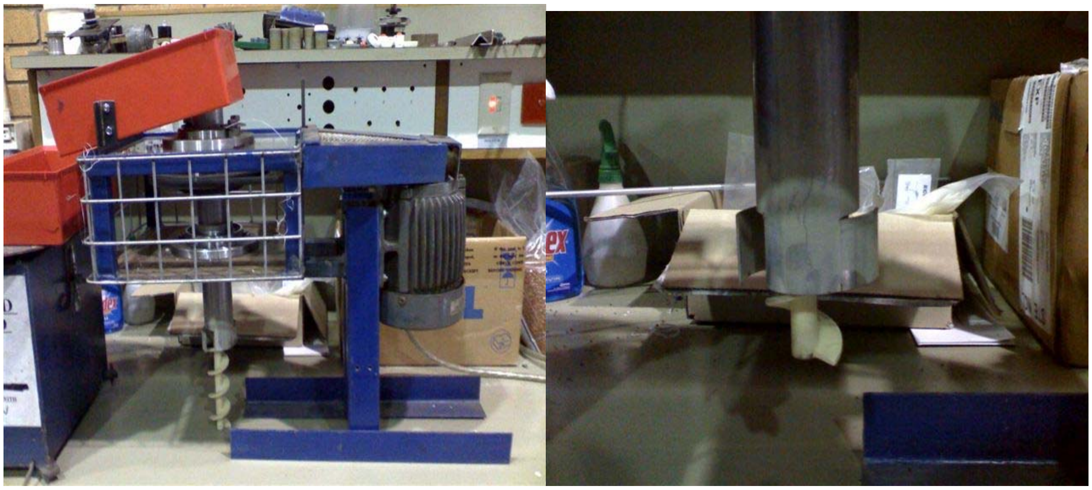

Figure 3a and 3b – Photos of experimental rig

Figure 3a shows an overall view of the test rig without the feed chamber. The removal of the feed chamber has allowed the screw flight to drop down and be clearly visible. Figure 3b shows a close up of the feed point of the elevator. The cutters are evident and again the screw flight is shown in a dropped position. The bottom of the screw flight in operation is flush with the bottom of the tube.

4 Vertical Conveying Tests

Initial baseline testing was conducted with the elevator in a vertical orientation and involved testing over a range of tube speeds, a number of screw diameters, and a number of cutter heights. The results of this testing work are presented in the following graphs.

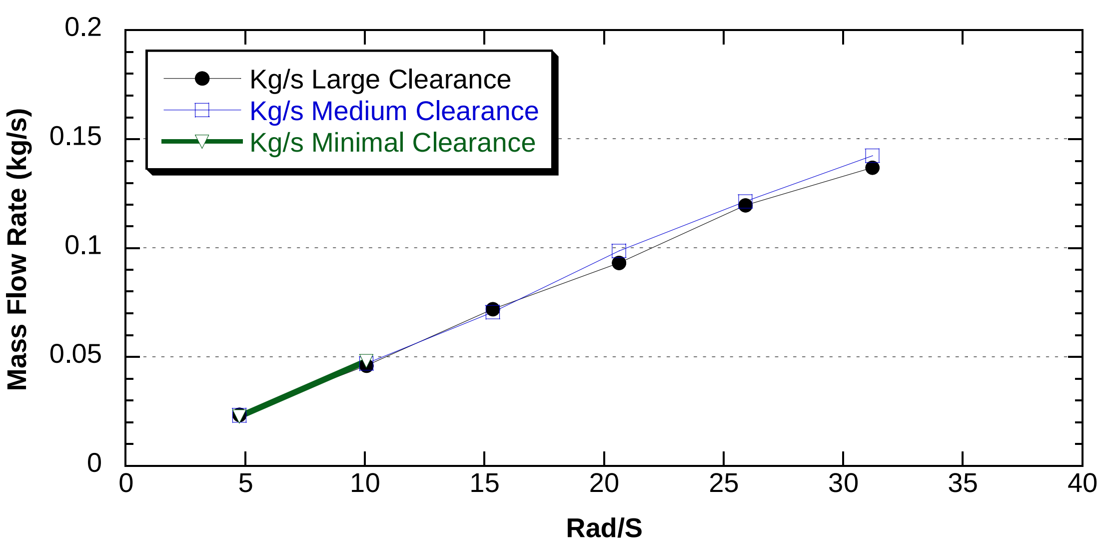

Figure 4 - Experimental mass flow rate versus tip clearance for vertical conveying of Sorghum – Average flow rates only plotted.

Figure 4 presents the mass flow rate data collected in the laboratory for the three different tip clearances tested. Most striking about the laboratory data is the conformity of the different clearance conditions indicating that at this scale, and for the bulk materials tested, there is seemingly little advantage of a close fitting screw over a comparatively loose fitting screw. This is viewed as significant advantage by the authors.

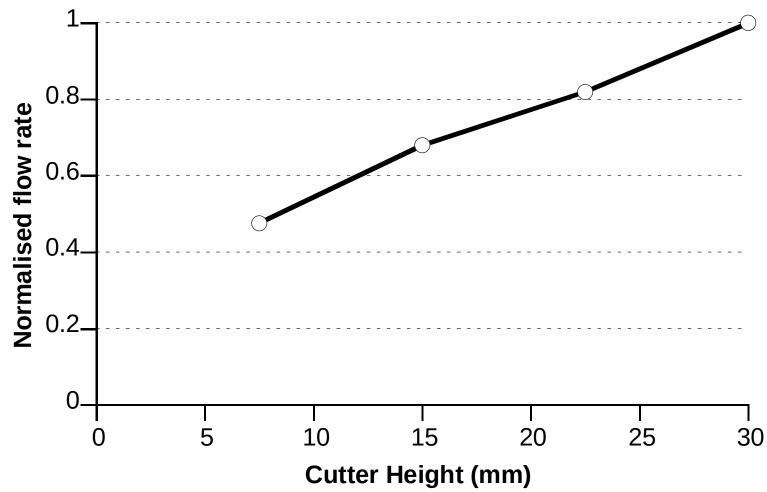

Figure 5 – Normalized flow rate of bulk solid as a function of the cutter heights.

Figure 5 presents an interesting outcome from the experimental work which requires further investigation. This outcome is a flow rate that is not directly proportional to the cutter height. Consider that at a cutter height of 30mm the flow rate is normalised to unity. At a cutter height of 15mm, the total mass flow rate is some 65% of the previous case. At this stage our belief is that this is partially a result of entry blocking with the taller cutters forcing an increasing percentage of material to evade capture by the cutters by creating a shear plane in front of the cutter that facilitate particles to rise up over the cutters and remain in the bed. The bed upheaval is clearly evident in both the physical and discrete element models [2]. The DEM work in progress indicates that this upheaval is a function of bed depth and an increasing bed depth leads to a reduction in bed disturbance.

Obviously at some non zero cutter height the flow rate will drop to zero as individual particles become unable to enter the aperture. The form of the graph between the lowest height cutter tested/simulated and the zero flow point is not currently defined.

The results for the conveying of Wheat were almost identical to the Sorghum indicating that the mass flow rate of product, in the case of Wheat and Sorghum is insensitive to the shape effects. The slightly higher density of the Wheat is countered by a lower packing efficiency providing an overall mass flow rate very similar to the Sorghum.

5 Particle Damage

Clearly with reduced tip clearance and given the typical shape of the cutters, a pinch point is created between the diminishing cutter and the screw flight. Figure 6 illustrates the pinch point.

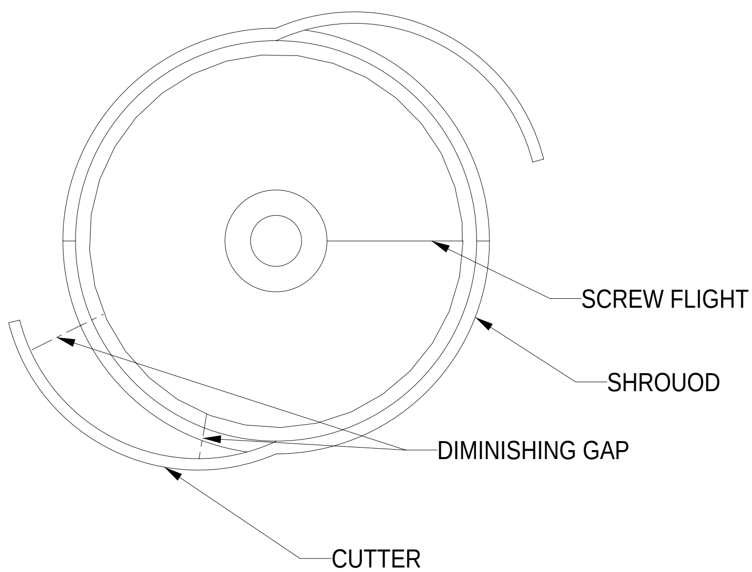

Figure 6 – Diagram of pinch point where cutter potentially jams material against the screw flight.

The initial view of this diminishing gap leads to an assumption that particles greater in diameter that the radial clearance have a moderate probability of damage at the entry point to this device. However the experimental testing has shown very low attrition with the Sorghum.

Both Sorghum and Wheat particles were tested for both rupture strength and rupture mode in a displacement controlled materials testing machine. These measurements showed that both particle types had a very similar rupture strength though the Wheat particles held their particle shape very well post failure. The Sorghum particles ruptured internally and readily broke into several smaller sections. This was ideal for determining the extent of particle damage with the OLDS elevator.

Each test involved the elevating of approximately 12000 particles (1 kg) and with little correlation to the screw clearance, sieve analysis at the end of each experiment showed on average 2-3 damaged grains. From this is would seem that the pinch point illustrated in Figure 6 is of minor significance in respect to particle damage.

6 Inclined Conveying Tests

One of the underlying reasons for this investigation was to evaluate the OLDS unit as a potential device for the feeder of filter cake into exhaust gas streams for drying. This process has inherent problems associated with the filter cake becoming compacted prior to discharge to the flue gas causing process difficulties. An equally significant issue is the formation and maintenance of a gas seal to prevent/limit exhaust gases entering work spaces. If using a horizontal screw feeder this involves level detection and cycling of the screw speed. It was the OLDS elevators inability to fully self clear with the free flowing materials that prompted the investigation into inclined conveying.

Although it may be possible for the discharge from a vertical OLDS elevator to be discharged via a chute into the gas stream for drying this may not always be a practical solution. If the OLDS elevator will operate successfully at an inclination without fully clearing (thus forming a permanent gas seal), and still provide the evenness of flow observed with the vertical unit then this unit may solve a broader class of engineering problems, such as the filter cake feeding.

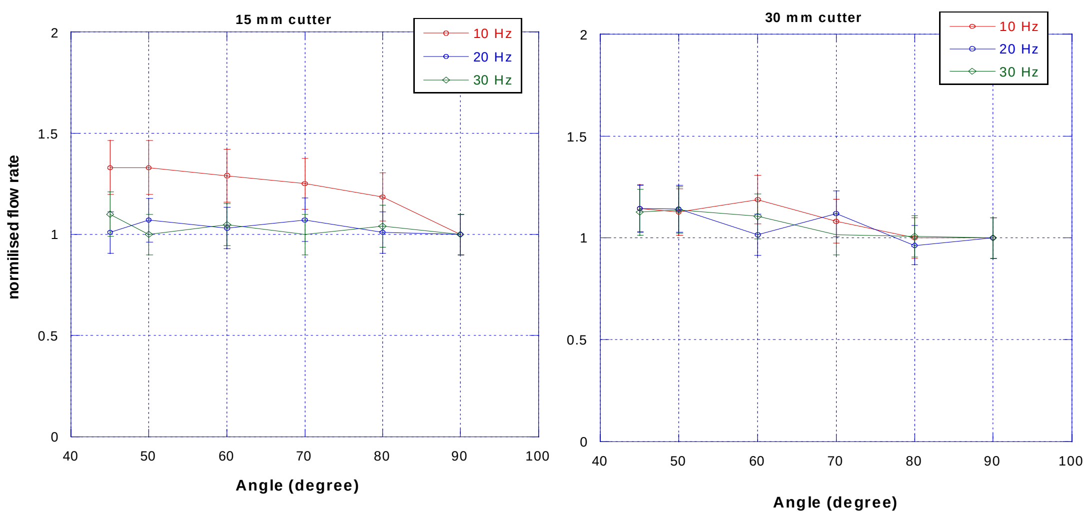

Figure 7a,b Normilised Mass flow rates as a function of inclination a) 15 mm cutter b) 30 mm cutter

From Figures 7a and 7b it can be seen that the normilised flow rate at non vertical orientations is typically improved compared with the vertical operation. There is a moderate amount of noise in the captured data predominantly as a result of using the Variable Voltage Variable Frequency (VVVF) drive unit. This is an unfortunate necessity of the experimental facility and is principally responsible for the size of the error bars in the data.

Observations of the flow indicate that self clearance does not occur within the range of inclinations tested to any significant level over the vertical orientation. It would appear to have retained a high level of federate linearity with a doubling of rotation speed providing essentially a doubling of the mass flow rate for any of the tested inclinations.

When the feed chamber 'runs dry' the material within the elevator column essentially ceases transport and forms a plug of material within the column. This plug we expect to present a reasonable pressure drop and may allow an OLDS elevator based filter cake feeder to require very limited control devices and be intrinsically safe in terms of gas emissions into the workplace.

7 General Observations

The mode of operation within the OLDS elevator would appear to be inherently gentle on the product conveyed. The mechanics of operation dictate that particle elevation is caused by the propagation of shear stress from the wall of the shroud to the bulk material and essentially rolls/drags the bulk material along the flight surface. As a result of this the bulk material will be in a state of low consolidation stress, much lower than for a screw conveyor/feeder/elevator where the bulk material is forced to shear against the wall. This has a significant advantage for the feeding of compressible and cohesive materials which should result in the material not forming clumps as readily as would be seen with a screw feeder. This will directly improve the process and hopefully negate the need for active or passive methods for breaking the clumps before being discharged into the gas stream.

The transport efficiency as determined from the experimental data would appear to be very high. For each tube rotation the material is elevated approximately 0.75 of the flight pitch, Ve=0.75 which seems to support the results presented by Bates [1].

8 Conclusions

Our experimental testing of an OLDS type elevator have shown

- A linear relationship of federate with tube speed.
- A relative level of insensitivity to tip clearance in overall performance.
- A non-linear response to cutter geometry/height on the material throughput which is an area of interest for further research.
- A small variation in the flow rate of solids with inclination angle.
- A continuing inability for the tube to fully clear despite the inclination angle facilitating the use of this device for filter cake feeding.
- A very high transport efficiency perhaps enabling a smaller overall device for a given tonnage rate requirement.

From these observations we conclude that the OLDS style elevator has potential as a filter cake feeder that warrants much more attention.

There is significant scope for further research into the optimization of the feed cutters to either maximize bed disturbance or minimize bed disturbance depending on the specific needs of the particular bulk material.

9 References

Bates, L. “A revolutionary, non-revolving screw elevator”, Solids and Bulk Handling, Vol. 31 (2005).

McBride, W. Cleary, P.W. – “An investigation and optimization of the ‘OLDS’ elevator using Discrete Element Modeling”, Proceedings of Discrete Element Methods 07. Brisbane, Australia August 27-29, 2007.