

Bulk Material Belt Conveyor Transfer Point Simulation of Material Flow Using DEM

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Summary

Computer simulation of conveyors and the dynamics of bulk material flow problems help engineers' design more efficient and reliable belt-conveyor transfers and chutes. As computer hardware and software continues to advance, simulators will only become more common in the design process and no longer will engineers need to rely on rule of thumb engineering and past experience.

One engineering design tool which now leads the way in bulk material handling analysis of transfers and chutes is Chute AnalystTM, a software application which integrates the Discrete Element Method (DEM) and Computer Aided Design (CAD). Note that the 3D DEM modules are a further development of the research performed by Mustoe and co-workers, see references [1,2]. The Discrete Element Method (DEM) is a numerical analysis tool for the mechanical analysis of a system of interacting particles or bodies, see references [3,4]. In the DEM particle, movements are integrated with time, using the equation of motion. The results from a DEM model provide a detailed evolution of the particles motion, interaction forces and stresses over the duration of the analysis. These features make the DEM a very powerful tool for analyzing bulk material-handling problems as it explicitly models bulk material flow and its effects on the transfer and chute structural elements. One practical use of this new integrated DEM/CAD technology in the field of bulk material handling and in the analysis and design of belt-conveyor transfers.

This paper will describe the problems associated with Belt-Conveyor Transfer points and new design techniques using Chute AnalystTM (see Figure 1 and Figure 2 for typical transfer point examples).

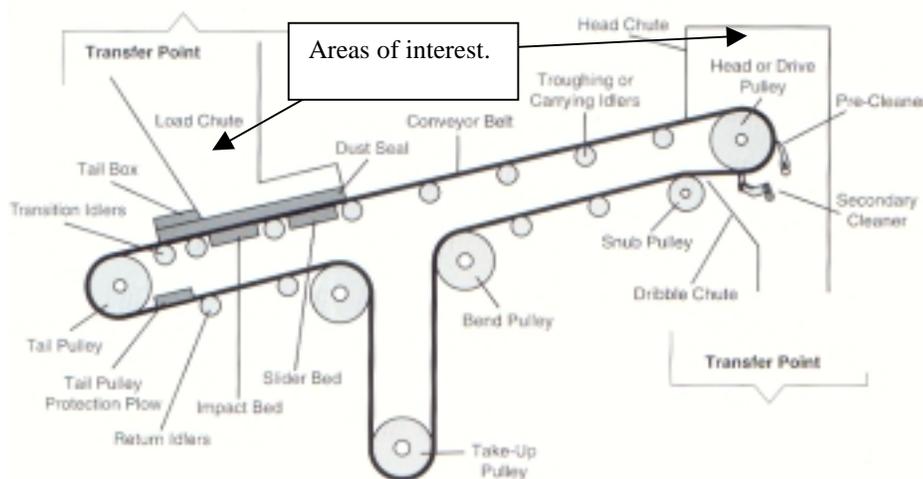


Figure 1, Typical conveyor system components and chutes.

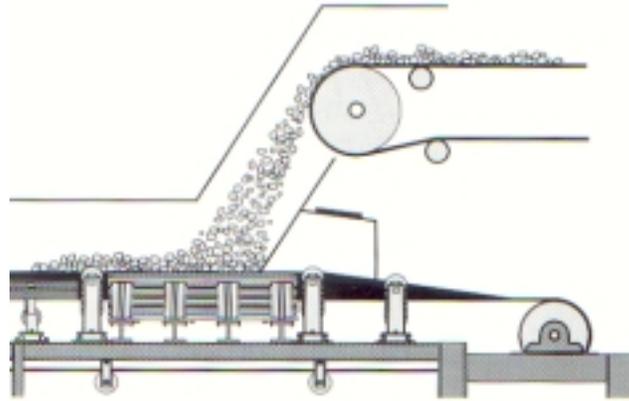


Figure 2, Typical transfer point, everyday solution by past engineering practices.

In particular we want to answer four fundamental questions:

1. What is a bulk material belt-conveyor transfer point?
2. Why do we have bulk material belt-conveyor transfer points?
3. What are the major problems associated with bulk material belt-conveyor transfer points?
4. How do we go about designing and creating a "real world model" of a transfer point with DEM?

What is a bulk material belt-conveyor transfer point?

A transfer point is the location on a conveyor where the material is loaded or unloaded. A typical transfer point is composed of metal chutes that **guide the flow of material**. In most real life applications, problematic material flow conditions occur because the design of transfer points often rely on rule-of-thumb techniques and years of experience. This approach often leads to arcane solutions that require field modification and costly maintenance.

The design of a transfer point will greatly affect the life of components as well as maintenance costs and safety. The design of chutes and other loading equipment is heavily influence by conditions such as the capacity, size, vertical drop, characteristics of the material handled, speed and inclination of the belt and whether it is loaded at one or several locations. An ideal transfer point would be designed to take into account the following:

- Center load the material
- Load material at a uniform rate
- Load material in the direction of belt travel (receiving conveyor)
- Load material at the same speed the belt is moving (receiving conveyor)
- After the belt is fully troughed
- Load material with minimum impact

At the same time, the transfer point structure has to prevent:

- plugging
- chute wear and belt wear
- the creation of dust
- material spillage

Ideal transfer point chutes are very difficult to achieve by rule-of-thumb engineering, as most chute geometries are unique and cannot be tested at full-scale or optimized in a laboratory or workshop. As such,

most users live with unfortunate problems which lead to high maintenance costs and retrofits. This is where Chute Analyst™, and computer simulation of bulk material flow has become an important technical advancement.

Why do we have bulk material belt-conveyor transfer points?

There are certain limitations on the physical length of a conveyor. A number of technological advances in the recent years have allowed mines/plants to build longer continuous conveyors. Better belting and modern drives have contributed to these longer systems. However, no matter how good conveyor technology becomes, system length, lift and capacity requirements will continue to demand more efficient transfer points.

What are the major problems associated with bulk material belt-conveyor transfer points?

Most of the major problems with bulk material belt-conveyor transfer points can be attributed to problems with the original design, field retrofits and the low priority given during the design process. It is common for the transfer point to be the last part of a belt conveyor system designed almost as an afterthought. Although the transfer point is a vital part in the control of bulk material flow. Some of the major problems that mines/plants have with transfer points are:

- Plugging - Stops the entire operation. See figure 3 and 4.
- Spillage - Corrosion, extra cost of maintenance and most importantly safety (one-half of all the accidents that occur around belt conveyors in mines are attributable to cleanup and repairs required by spillage and buildup per MSHA statistics). See figure 3 and 6.
- Belt Wear - Poor chute design can reduce belt life by as much as 75% and belting is the largest cost of the conveyor system. See figure 5.
- Chute Wear - As conveyor throughputs become larger, the down time to fix and repair a chute will not only be a direct maintenance cost but a lost of production, directly impacting the output of the facility. See figure 8.
- Material Degradation - Leads to dust generation, reduction in the quality of the material and in some extremes the cause of a fire or an explosion. See figure 7.



Figure 3, Plugging and Spillage.



Figure 4, Plugging.



Figure 5, Belt wear, impact damage.



Figure 6, Spillage.



Figure 7, dust generation and material degradation.



Figure 8, Chute wear on the sides.

How do we go about designing and creating an "accurate virtual world model" of a transfer point with DEM?

Chute Analyst™ is a design tool utilizing DEM/CAD technology that provides computer simulations of material flow in actual industrial transfer points. It enables the engineer to design a chute, simulate the material flow through it and optimize chute geometry. It has been used since 1997 to model an extensive number of new and existing transfers and chutes in a number of mines and facilities. These analyses have simulated many different geometries and various materials, including run-of-mine and clean coal, copper/gold ore, sulfur, coke, aggregate and many more.

The typical process that a designer and/or engineer performs to retrofit an old or design a new transfer points are, see references [5]:

Transfer Chute New and/or Retrofit Design Steps

1. Render accurate 3-D CAD representation of old transfer or new transfer
 2. Identify chute geometry restrictions and manufacturing limitations
 3. Identify project goals (i.e. dust emissions, flow restrictions, etc)
 4. Identify material properties and develop representative particle description
 5. Make design changes to chute geometry with CAD
 6. Simulate performance using Chute Analyst™
 7. Evaluate simulation results
 8. Detail Design
 9. Manufacture
 10. Installation
- Iterate ↪

A good example of a transfer chute retrofit project is conveyor BC400, at Freeport/McMoRan's Grasberg Mine in Indonesia (one of the world's largest copper/gold mines). This existing chute had been in place and operating for several years. This application seemed to be a very simple chute that could have been successfully designed using rule's-of-thumb. However, this transfer chute had a very poor operational performance history with high maintenance expenses.

The original geometry and overall chute layout is shown in figures 9 through 16.



Figure 9, Front head chute



Figure 10, Head chute



Figure 11, Receiving Chute

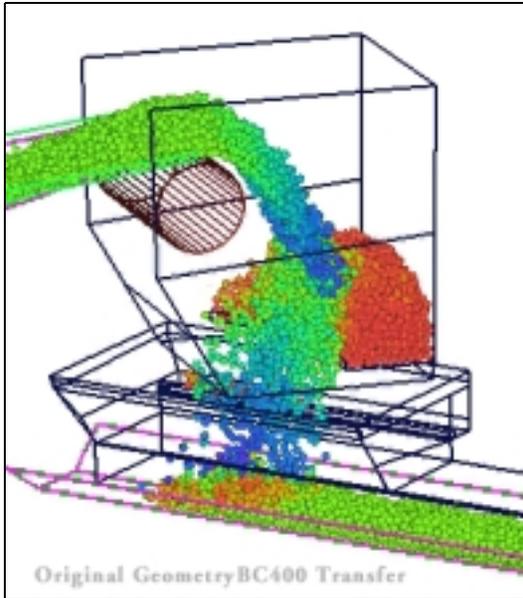


Figure 12, Original geometry with material flow.

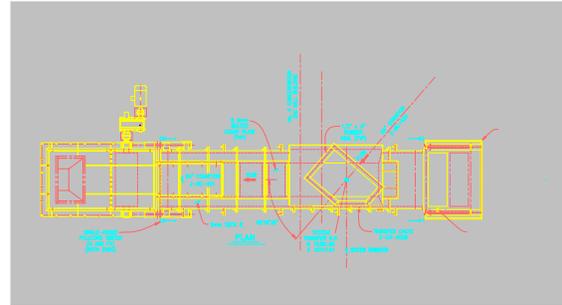


Figure 13, Original Geometry.



Figure 14, Material Over Head Pulley



Figure 15, Back Iso Receiving Chute



Figure 16, material in rock box

As it can be seen from figures 9 through 16, the original chute was made up of two sections, upper chute (head chute, see Figure 12, Figure 10 and Figure 9) and lower chute (receiving chute, see Figure 12, Figure 11 and Figure 15). The upper chute had a rock box in it that was used to protect the sides and front of the chute from material wear and at the same time redirect the material flow down into the lower chute. The lower chute had a slanted side and a rock box as to protect the sides of the chute, with vertical sections that would mate with the skirting of the chute to help to center load the receiving belt-conveyor. It looks like a very straightforward chute with the angle between the incoming and outgoing conveyor of 130.72 degrees. The major problems that were reported by the mine site were as follows:

- The material position on the receiving belt-conveyor was not center loaded.
- The receiving conveyor belt was wearing out prematurely (3-4 months at an extreme replacement cost to the mine.).
- Extreme build-up of material in the chute, in some cases leading to plugging.

Using the nine step criteria mentioned previously.

1. Render accurate 3-D CAD representation of old transfer. A 3-D DEM model of the existing transfer was created and validated with simulations (see Figure 12 and Figure 13). The preliminary analysis clearly showed why the material flow was wearing out the belt, building up high in the upper and lower chute rock-boxes and not center loading. The rock boxes were designed in such a

way as to allowed the material to spread out and fill and not as guiding surfaces. In addition, the material was flowing in the opposite direction of the receiving conveyor causing a premature wear of the belt and skirting. As for center loading, the material from the first rock box was not flowing vertically down but to one side. The lower rock box in the lower chute forcing the material even more to the side with most of the material being forced to one side on the receiving conveyor.

2. Identify chute geometry restrictions and manufacturing limitations. It was determined that the new chutes had to fit insides the geometry of the existing transfer point. In addition, it had to reduce the belt wear, chute wear and be easy to maintain. Also the manufacturing of the chute had to be easy and the Freeport staff had to be able to manufacture it on site. Most of the liners and existing parts had to be used.
3. Identify project goals (i.e. dust emissions, flow restrictions, etc). The project goals were set as follows:
 - The chute could not plug under all weather and material conditions, dry, wet, more fines, more rock, etc.
 - Minimize belt and chutes wear; optimize the chute and belt life.
 - Center-load the receiving conveyor during all load conditions from a minimum of 2500tph to the maximum of 7500tph.
 - The maintenance and replacements of the chute was to be kept to a minimum with a very short down time.
 - Minimize dust generation.
4. Identify material properties and develop representative particle description. It should be mentioned here that this was the first time we did model this type of material, copper/gold ore in an extreme environment conditions ranging from very dry to very wet with varying material size distribution from extremely large to fines. The way we approached this was to model the existing transfer with different material properties and comparing the analysis with real word. It turned out that we were very successful in doing that and quickly had the general material properties that corresponded to the Freeport McMoRan copper/gold ore and gave us accurate results with quick analysis time. See Figure 14, Figure 16 for material example before the analysis and see Figure 17 for material out of the new BC400 chute onto the receiving conveyor.

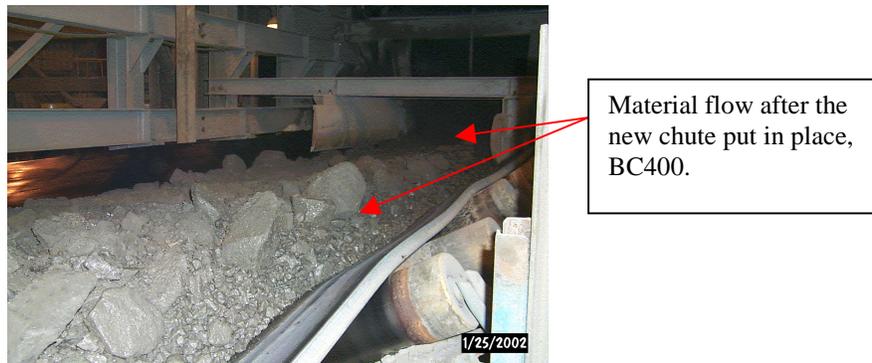


Figure 17, Material on BC401 conveyor belt from the new BC400 chute.

5. Make design changes to chute geometry. Finally, we were ready to start with the modifications to the chutes and the material flow. We decided on a number of geometry's that might best work in this case. Two that stood out were rock box concept in the upper and lower chute sections and a rock box in the upper section with a slide in the lower section. The rock-box only concept was familiar to everyone but had its own drawbacks and benefits. Some of those drawbacks are:

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- a) Material continues to come to a stop at every rock box and has to be accelerated through a vertical drop to finally reach the receiving conveyor speed. Might require a very tall chute.
 - b) Material fans out in every rock box, filling them up with changing material conditions it is possible to fill the rock boxes high and create plugging in the chute.
 - c) With changing material properties it is possible to have the rock boxes filled skewed leading to off center loading.

Some of the benefits of the rock-box only concept were:

- a) The chute was well protected by the material, low wear of the chute.
- b) Easy to manufacture.
- c) Everyone knew this and felt at easy with it, easy to sell and implement.

The upper chute rock-box and lower chute slide was a system that everyone was not quiet sure what to expect from but from a material flow point was a better choice. The drawbacks of this geometry are:

- a) Lower slide is exposed to direct material flow, will experience more wear than a rock-box.
- b) No one has used this in this extreme material application.
- c) Harder to design and manufacture.

The advantage or benefits of this type of system are:

- a) Material flow abstractions are minimized.
- b) Vertical drop in the chute required to reach the receiving conveyor velocity is less than the rock-box only approach.
- c) The material flow is better controlled and guided, and positioned onto the receiving conveyor with more accuracy and with fewer dependents on the varying conditions.

6. Simulate performance using Chute Analyst™. Now came the real question can Chute Analyst™ with the help of DEM technology help us fix the problems and create a real life transfer that will do all of the things an ideal transfer is suppose to do. Based on our previous experience and designs we decided that the best approach to material flow is to keep the material flowing by minimizing any abstractions to the flow. After doing a number of simulations, it turns out that this was no longer a simple transfer but a very complicated one when you take into account belt wear, chute wear, material velocity and the redirection of the continuously flowing material, especially at the large flow rate of 7500tph. At this point, it was obvious why engineers in the past might have had problems designing an ideal chute in this case with out the help of such technology as DEM. (See Figure 18, Figure 19 and Figure 20 show examples of some of the analysis that we have done.)

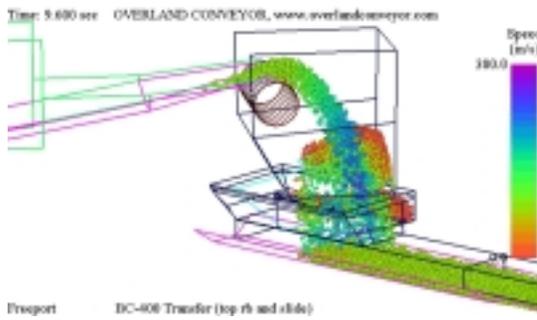


Figure 18, Test Case, rock box concept.

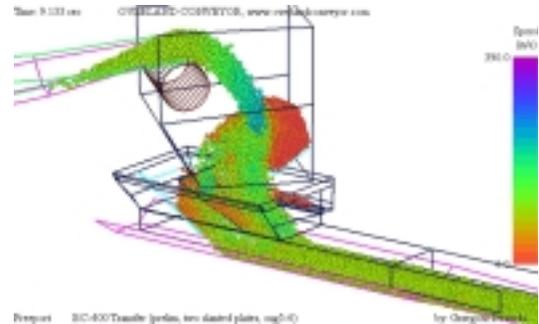


Figure 19, Test Case, rock-box two slides.

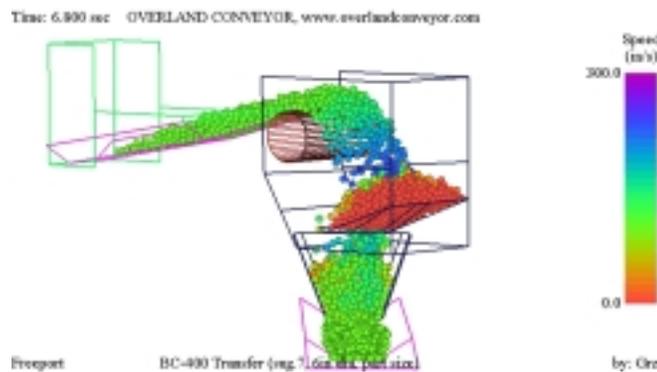


Figure 20, Test Case, Slanted Rock-box slide.

- Evaluate simulation results. After running multiple geometry and variations of them and reviewing them. We could see what the different geometry and changes to it did to the material flow and after a multiple iterations of step 5, 6, 7 we finally came up with the geometry that worked the best for this design and satisfied the goals of this project. The final geometry was a simplified version of the slanted rock box and slide concept. The rock box was made horizontal to simplify the manufacturing concerns. (See Figure 21 and Figure 22.)

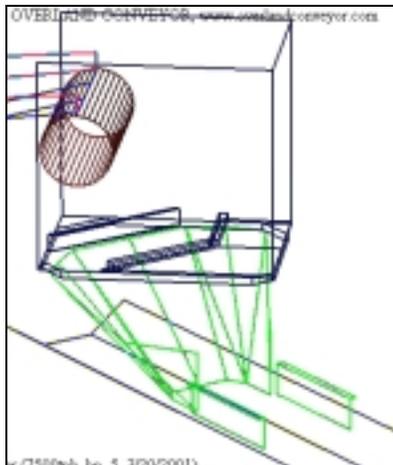


Figure 21, Final Geometry, BC400 Chute.

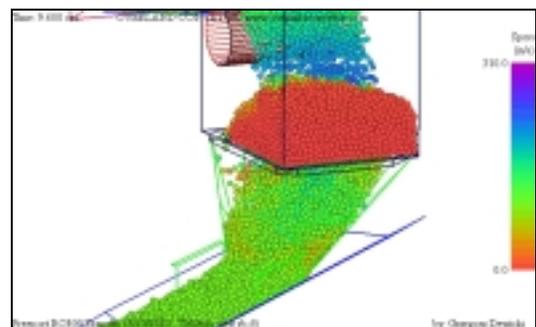


Figure 22, Final Geometry, BC400 Chute with material, 7500tph.

- Detail Design. Conveyor Engineering of Boise, ID did the detail drawings of the transfer point from the 3D wire-frame drawings of the chute that was produced from the analysis and simulation

work. (See Figure 23, Figure 24 and Figure 25 for the drawings showing the final Slide and Chute after the analysis.).

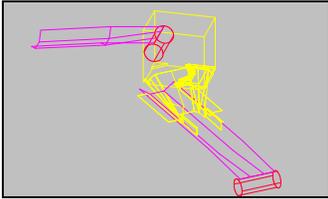


Figure 23, BC400 Chute 3D wire-frame.

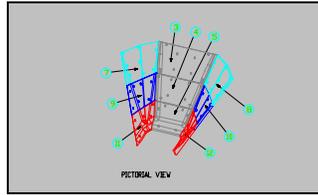


Figure 24, BC400 Slide, detail iso.

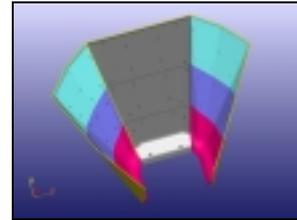


Figure 25, 3D solid of BC400 Slide

9. Manufacture, most of the chute was manufactured on site with few minor modifications to make it easier and to expedite the manufacturing to meet the dead lines.
10. Installation. This was done on the site with no interaction from us with the personal of Freeport McMoRan following the blueprints.



Figure 26, BC400 slide Liners.



Figure 27, BC400 Chute Inside, looking down from the top.

In conclusion, this paper has shown that a new engineering analysis software system based on a combination of DEM and CAD technology is an effective engineering design tool. This new integrated DEM/CAD design methodology has been described in the context of industrial case study concerning the retrofit design of a mining transfer point system. The original transfer point had problematic material flow characteristics which lead to poor operational performance and high maintenance costs because of wear problems. Note the DEM/CAD re-designed transfer point has been operating very efficiently in terms of material flow with minimal wear and low maintenance costs for over the last year. (See Appendix A: Feedback from the mine site.)

References:

- [1]. Hustrulid, A..I. and Mustoe, G.G.W., "Engineering Analysis of Transfer Points Using Discrete Element Analysis", Proceedings of the Annual Meeting of the Society of Mining Engineers, Phoenix, Arizona, March. 1996.
- [2]. G.G.W. Mustoe and M. Miyata, "Material Flow Analyses of Non-Circular Shaped Granular Media using Discrete Element Methods," October, Journal of Engineering Mechanics, ASCE., Vol. 127, No. 10, pp 1017-1026., 2001.

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- [4]. Proceedings of the 2nd.. Int. Conf. on Discrete Element Methods,(J.R. Williams and G.G.W. Mustoe, Eds.), MIT Press, Boston, MA., USA, 1993.
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APPENDIX A: Feedback from the Mine Site.

Some of the feedback from the site has been extremely positive and encouraging. This far the chute in real life application has performed as it did in the simulation, as one of the comments from the site was, "John, The curved chute we just installed between 400 and 401 works exactly per the simulations - its scary it's so close." (Mike Mular- Freeport Indonesia Mill Manager)

The following is a brief list of questions that were asked of the mine site and the answers to them from the mine site after the chute was in operation for little over 3 months.

- Question? Have you had the opportunity to vary the tonnage rate much? Does the chute continue to center load under different tonnage rates?
- Answer: The chute loads on center at all times.
- Question? How long did it take construction to make the retrofit?
- Answer: Construction required 5 days, 120 hours to make the retrofit. This could have been reduced considerably. However it was done during the coil replacement, with the workload, man power and equipment was tight. I would say 72 hours would be sufficient under normal circumstances
- Question? How is the chute wearing? Where the cast F-type liners are? Where the 500bn wear plate is? Are there any isolated areas of wear?
- Answer: It is wearing surprisingly well. The highest wear area is the F type liners on the flat section, the bottom 3 rows and the wedge shaped liners on either side.
- Question? What is the liner wear life?
- Answer: As these are only 2-inch thick liners, the life is 3 months. We have made some changes to these to improve life. I have attached. The liners that were to be used and were designed in the chute were 3-inch thick but we just used the 2-inch thick liners to start with.
- Question? How do the wheels perform for rolling the chute back plate in and out?
- Answer: Engineering forgot to order the wheels so were not installed. These are scheduled for the next S/D in February. These will make maintenance for easier as we have a spare chute they may be rotated and rebuilt in the shop.
- Question? Is there a significant improvement in belt wear? What is your new belt life?
- Answer: The belt was also extended at the same time. To date there are no visible signs or wear. I would estimate 16 to 18 months belt life at this stage as compared to 4 months. The curved chute has definitely had the biggest impact on improving the belt life as compared to lengthening the belt.
- Question? Is there anything that we can do to improve on the next one?
- Answer: It is an excellent design, just need to improve on the liner design as attached.