The optimisation of transfer chutes in the bulk materials industry

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ABSTRACT

Bulk materials handling is a rapidly growing global industry. Immense challenges exist to improve the efficiency and cost effectiveness of transporting and handling bulk materials continuously. The nature and scale of bulk materials handling varies from country to country. This study specifically focuses on the handling of bulk materials in the mining sector.

Within this industry, transfer chutes are a key component used for transferring bulk material from one conveyor to another. Among other uses it can also be used under hoppers or silos to transfer material to conveyors, trains, trucks or ships. In a continuous effort to improve the efficiency of processes the industry is bombarded with transfer chute problems that include:

- blocked chutes
- high wear of liner materials
- spillage due to skew loading
- conveyor belt wear at loading points.

Thorough investigation of existing transfer points, before modifying or replacing them with another configuration, gives better insight into the problems. This aids the designer to come up with the optimum solution for a specific transfer point. In this dissertation a study is done on the configuration of dynamic chutes or hood and spoon chutes. After completing a detailed investigation of existing problems, the study focuses on rectifying material transfer problems and designing for ease of maintenance.

Adding to the improved flow in the new design, for the specific case study discussed in this dissertation, other design details are discussed which further validates the new design. This design improves the wear life of the liners inside the chute and minimises down time by reducing maintenance shutdowns.

There are literally endless possibilities when it comes to chute configurations due to the uniqueness of each plant, material type and layout constraints. It is therefore beneficial to know what issues to address in the process of chute design or optimisation.

This study focuses on a specific case study with unique problems and solutions. It should however give further insight and a basic understanding of what a chute designer must consider, and the methods taken, to optimise an existing material transfer point. The purpose of this document is therefore not to provide the reader with a recipe for chute optimisation but rather with the knowledge to comprehend the problems and solutions by discussing a specific industry case study.

SAMEVATTING

Materiaal handtering is ‘n vinnig groeiende wêreldwye industrie. Hierdie industrie word gekonfronteer deur groot uitdagings om die effektiwiteit van materiaal handtering te verbeter en sodoende die koste daaraan verbonde te verminder. Die aard en skaal van materiaal handtering varieer van land tot land afhangende van die vereistes wat gestel word deur daardie land se industriële sektor. Hierdie studie fokus spesifiek op materiaal handtering in die mynbou sektor waar hoofsaaklik geprosesseerde erts handteer word.

In hierdie industrie is oordrag geute ‘n sleutel komponent en word dit hoofsaaklik gebruik om erts te vervoer vanaf een vervoerband na ‘n volgende. Dit kan ook onder andere gebruik word onder hoppers of sillos waar materiaal vervoer word ‘na vervoerbande, treine, vragmotors of skepe. In die strewe om die effektiwiteit van prosesse te verbeter word die industrie gekonfronteer met probleme wat onder andere insluit:

- geblokkeerde oordrag geute
- hoë slytasie op geut-voerring materiale
- vermorsing van materiaal as gevolg van geute wat skeef aflaai op vervoerbande
- hoë slytasie van vervoerbande by uitlaai punte

Voordat bestaande probleem geute vervang word met ‘n nuwe konfigurasie is dit belangrik om ‘n deeglike ondersoek te doen. Hierdie ondersoek skep ‘n beter insig oor die probleme wat bestaan in die oordrag geute. ‘n Beter insig rondom die probleme gee aan die ontwerper die vermoë om die optimale oplossing vir die probleme te kry. In hierdie skripsie is ‘n studie gedoen oor die konfigurasie van dinamiese geute of sogenaamde “hood and spoon” geute. Bestaande probleme word in ag geneem en die studie fokus op die verbetering van materiaal vloei sowel as ‘n ontwerp wat instandhouding vergemaklik.

As 'n toevoegsel tot die verbeterde vloei binne die nuwe ontwerp, vir die spesifieke geut waarna gekyk word in hierdie studie, word daar ook ander ontwerp toevoegings bespreek wat die waarde van die nuwe ontwerp verder bevestig. Hierdie ontwerp verbeter die leeftyd van die geut-voerring en tyd wat afgestaan moet word aan instandhouding word geminimeer.

Daar is letterlik eindelose moontlikhede wanneer dit kom by die konfigurasie van oordrag geute as gevolg van die uniekheid van elke aanleg, materiaal tipe en uitleg beperkings. Daarom is dit voordelig om te weet waaraan aandag gegee moet word in die proses om geute te ontwerp of te optimiseer.

Hierdie studie fokus op 'n spesifieke oordrag geut binne 'n spesifieke industrie met unieke probleme en oplossings. Dit behoort die geut ontwerper te bekwaam met die basiese kennis en insig oor waarna om te kyk wanneer geute ontwerp of geoptimiseer word. Die doel van hierdie skripsie is dus nie om die leser te voorsien van 'n resep om geute te optimiseer nie maar wel die kennis om die probleme en oplossings te verstaan deur gebruik te maak van 'n studie uit die industrie.

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TABLE OF CONTENTS

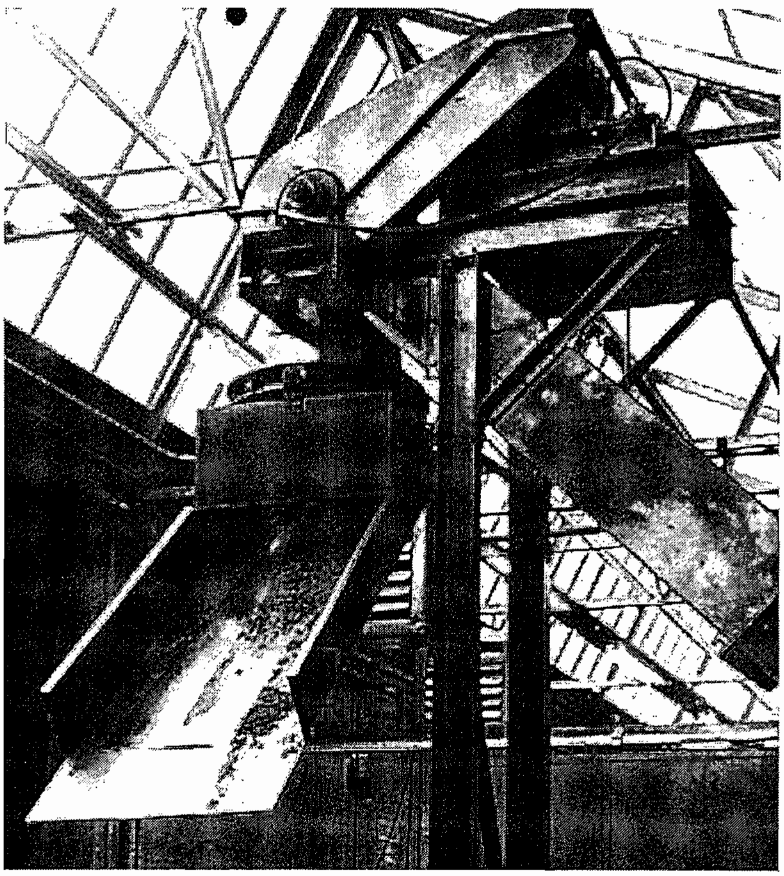
LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

SCADA	Supervisory Control And Data Acquisition
CCTV	Closed Circuit Television
CEMA	Conveyor Equipment Manufacturers Association
CV	Conveyor
DEM	Discrete Element Method
kPa	Kilopascal
mm	Millimetres
MSHA	Mine Safety and Health Administration
m/s	Metres per second
mt	Metric Tons
MW	Megawatt
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
R_c	Radius of curvature
R & D	Research and Development
t/h	Tons per hour
3D	Three Dimensional

CHAPTER 1: INTRODUCTION TO TRANSFER CHUTES IN THE BULK MATERIALS HANDLING INDUSTRY



1.1 INTRODUCTION TO TRANSFER CHUTES

1.1.1 *Bulk material handling industry*

In order to comprehend the utilisation of transfer chutes fully it is imperative to first understand the industry in which it is used. Transfer chutes are most commonly used in the bulk materials handling industry. Bulk materials handling operations perform a key function in a great number and variety of industries throughout the world as stated in 1978 by Arnold, McLean, and Roberts [1].

The nature of materials handling and scale of industrial operation varies from industry to industry and country to country. These variations are based on the industrial and economic capacity and requirements of the specific industry or country. Regardless of the variations in industry, the relative costs of storing, handling and transporting bulk materials are, in the majority of cases, very significant.

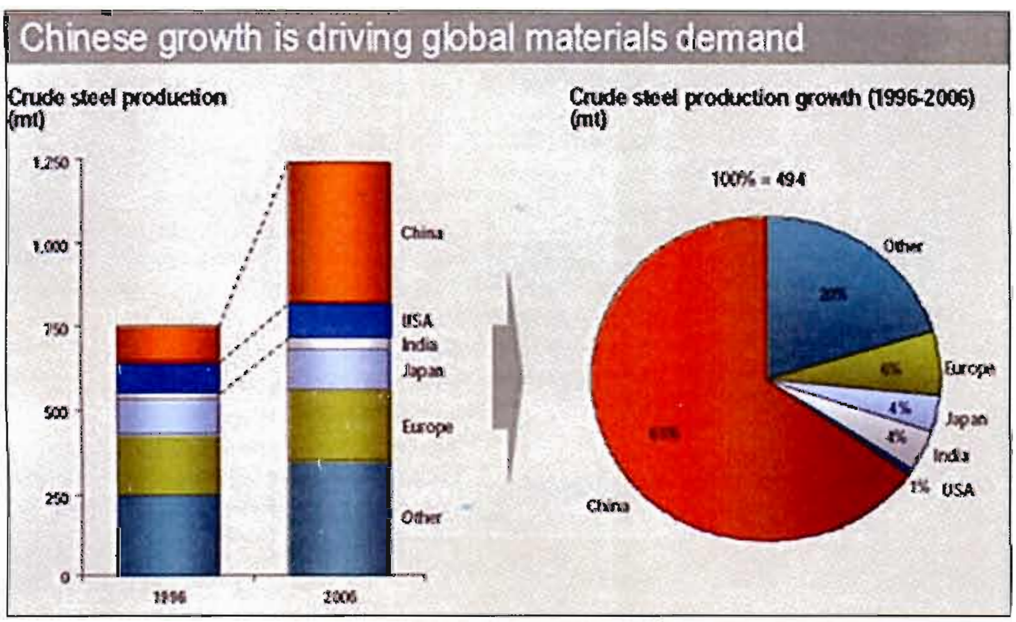


Figure 1: *Growth in global crude steel production from 1996 to 2006 [2]*

The chart from BHP Billiton, shown in Figure 1, provides a clear indication of the actual drivers of global materials demand. Figure 1 indicates the percentage growth in crude steel production from all the major role players between 1996 and 2006. China accounted for 65% of the 494 million tonnes of global steel production growth between 1996 and 2006. Europe grew by 6% while the "other" countries grew by 20% [2].

These figures emphasise that bulk materials handling performs a key function in the global industry and economy [1]. Because of market requirements, new products continuously evolve. This is also true for the field of bulk conveying technologies [3]. It can be assumed that the evolution of new technology is due to the requirement for more efficient and cost effective operation.

The case study which will be discussed from Chapter 3 onwards is an iron ore export facility. This facility exports approximately 50 million tonnes per annum. With each hour of down time, the financial losses equate to approximately R750 000. This highlights the fact that handling systems should be designed and operated with a view to achieving maximum efficiency and reliability.

1.1.2 *Function of transfer chutes*

BS2890 (*Specification for Troughed Belt Conveyors*) gives the definition for transfer chutes as follows: "A straight, curved or spiral, open topped or enclosed smooth trough, by which materials are directed and lowered by gravity" [4]. For any belt conveyor system to operate successfully the system requires that [5]:

- the conveyor belt be loaded properly
- the material transported by the conveyor is discharged properly.

The transfer of bulk material can either be from a belt, bin, hopper, feeder or stockpile and occurs at a transfer point. In most cases this transfer point requires a transfer chute [5]. In industry the most common use of transfer chutes is for transferring bulk material from one conveyor belt to another. This transfer of material can be done in any direction as simplistically explained in Figure 2 and Figure 3.

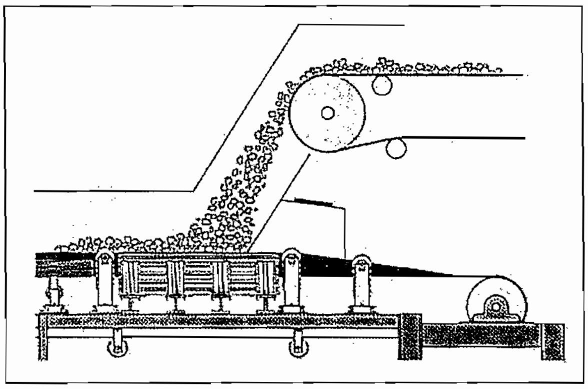


Figure 2: *Typical in-line transfer point [6]*

Figure 2 shows a basic in-line transfer of material from the end of one conveyor belt onto the start of another conveyor belt. Figure 3 illustrates a more intricate design where the direction of material transport is changed by an angle of 90°. This design, or any other design entailing a directional change in flow, normally requires more detailed engineering [7].

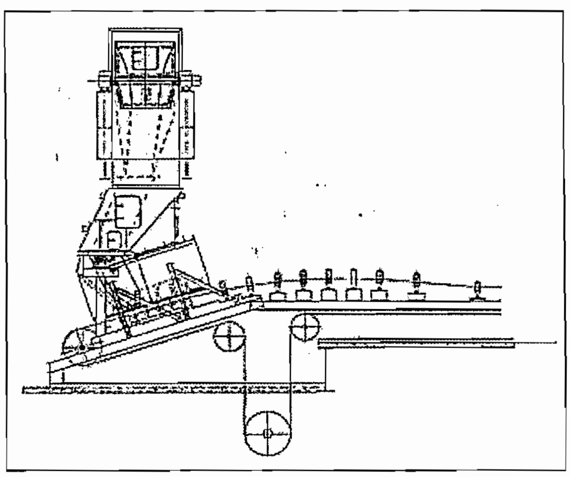


Figure 3: *90° transfer point [7]*

Regardless of the direction or type of transfer, there are some design requirements that always need special attention. Some of these requirements are reduced wear on chute liners, correct discharge velocity, minimum material degradation and minimum belt abrasion. The correct design will also eliminate blockages, shape the load correctly and minimise the creation of dust [7].

1.2 VARIOUS APPLICATIONS AND CONFIGURATIONS OF TRANSFER CHUTES

The application of transfer chutes is central to any operation in the bulk handling industry. Whether it is mining operations, storing, stacking, importing or exporting of bulk material, the transfer of material is always required. On the mining side the challenges involved with materials handling are probably some of the most extreme.

This is due to the great variation in lump sizes that must be catered for. At Sishen iron ore mine, seven iron ore products are produced, conforming to different chemical and physical specifications. The current mining process at Sishen entails [8]:

- Removal of topsoil and stockpiling
- Drilling and blasting of ore
- Loading of iron ore and transporting to the crushers
- Crushing and screening into size fractions
- Beneficiation of all size fractions
- Stockpiling onto various product beds.

The processes with the most intricate and complex chute arrangements are probably crushing and screening as well as stacking and reclaiming of material.

1.2.1 *Crushing*

An excavator or wheeled loader transfers the rock to be crushed into the feed hopper of the primary crusher. The primary crusher breaks the large rock boulders, or "run of mine" material, into smaller grain sizes. Some of the bigger crushers in the industry can crack boulders that are about one cubic meter in size. All the crushed material passes over a screen to separate the different lump sizes. The material that falls through the screen is transferred via a series of transfer chutes and conveyor belts to the stockpile area [9].

Where the material does not pass through the screen another system of transfer chutes and conveyor belts transfers this material to a secondary crusher. The material is fed into this crusher via a transfer chute from the discharge of a conveyor belt. All the processed material is then transferred to the stockpile area via a separate series of transfer chutes and conveyor systems [9]. Throughout this whole process the material lump size changes and with it the transfer chute requirements.

Figure 4: *Material lump sizes through a crushing plant*

Figure 4 shows some spillage from a conveyor between a primary and secondary crusher. The shovel in the picture provides a good reference as to the variation in material lump size on the walkway.

1.2.2 *Stacking and Reclaiming*

Normally the stockyard area has an elongated yard conveyor for moving bulk material in the longitudinal direction of the stockyard. Straddling the yard conveyor transversely is the rail mounted undercarriage of the stacker reclaimer. Three main chutes transfer material through the machine [10]. Figure 5 shows this machine in action while reclaiming material from a stockpile.

Figure 5: *Stacker Reclaimer in reclaiming mode*

The first chute will transfer material to the incline conveyor of the machine when the material has to be stacked on the stockpile. In the case where the material must bypass the machine, this chute will transfer material from the tripper, back onto the yard conveyor [10].

The second chute transfers material from the incline conveyor onto the boom conveyor. This is normally a difficult process because the boom conveyor is never in the same direction as the incline conveyor. From the end of the boom conveyor the material is simply discharged onto the stockpile [10].

When reclaiming stockpile material, the bucket wheel at the head end of the boom conveyor scoops up material and deposits it back onto the boom conveyor. From here it is discharged into the centre chute of the machine. This chute then discharges the material onto the yard conveyor for further processing. In some cases the bottom section of this centre chute must be moved out of the way to allow free passage of material discharged from the tripper chute onto the yard conveyor [10].

1.2.3 *Chute configurations*

Various chute configurations are used in the bulk materials handling industry. These configurations depend on the specific requirements of the system layout or material properties. There are basically two main configurations, consisting of dead box chutes and dynamic chutes. Both of these configurations have their specific applications in industry. The major difference is that dead box chutes use the material being transferred as a chute liner, whereas dynamic chutes are lined with a high wear resistant material. A combination of both can also be used.

If the material being transferred is relatively dry, such as gold ore, dead boxes prove to be more beneficial. One of the applications of a dead box is to absorb the direct impact of material discharged from a conveyor into a head chute as can be seen in Figure 6. Other applications are in long or high transfer points. In these transfers the momentum of falling material must be reduced before reaching the receiving conveyor belt in order to reduce wear of the belt [11].

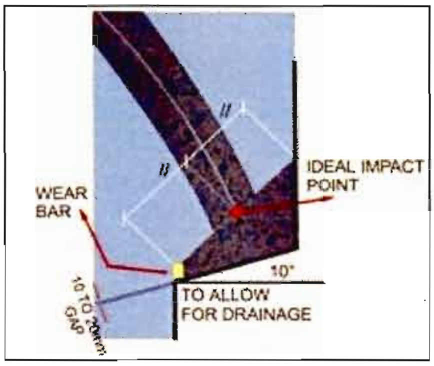


Figure 6: *Typical dead box [11]*

As shown in Figure 7 dead boxes are also used to accomplish changes in the vertical flow direction, by inserting angled panels. This configuration where dead boxes are used as deflection plates or impact wear plates is known as a cascade chute. In this case the deflection plate or the impact wear plate hardness is equal to that of the feed material [11].

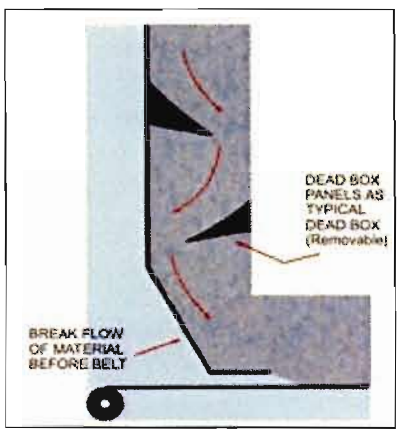


Figure 7: *Typical cascade chute [11]*

The hood and spoon chute or dynamic chute is configured so that the hood catches and changes the material trajectory path to exit with a vertical velocity. When the material impacts the spoon it slides down the smooth spoon surface. The material flow direction is changed to the direction of the receiving conveyor as shown in Figure 8 [12].

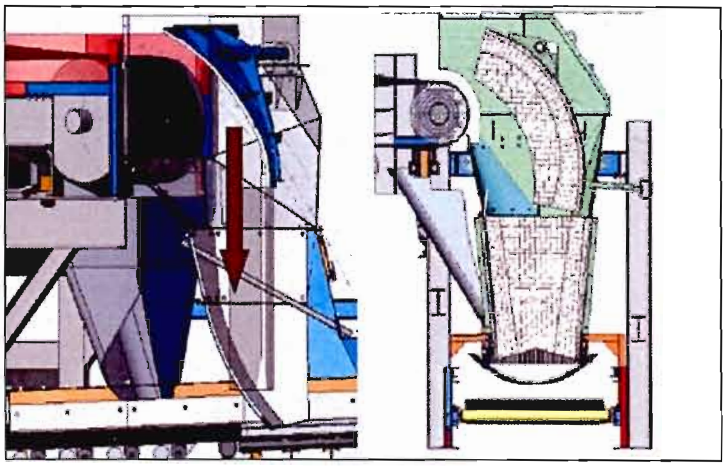


Figure 8: *Typical dynamic chute [12]*

Ancillary equipment used with this configuration of chutes is radial doors and flopper gates. Radial doors are used successfully below ore passes or silos for an on/off feed control as shown by Figure 9. One drawback of radial doors is the possibility of jamming while closing. In order to counteract this problem a knocker arm between the cylinder door and the rod can be added. This helps to close the door with full force, open with reduced force, or hammered open [11]

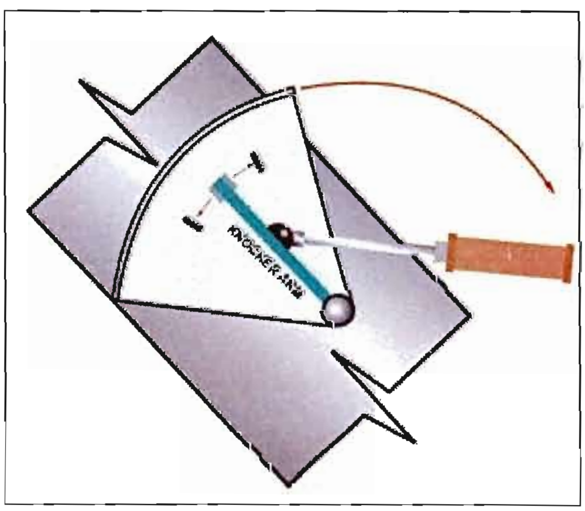


Figure 9: *Radial door used in chutes under ore passes or silos [11]*

The function of a flopper gate is to divert the flow of material in a chute when one conveyor is required to feed either of two discharge points as shown in Figure 10. For this same purpose a diverter car can also be used where a section of the chute moves in and out of the path of material flow. The critical area in the design of a flopper gate is the hinge point. In order for the gate to be self cleaning the hinge point should be placed above the apex of the double chute. This also prevents rock traps that can jam the gate [11].

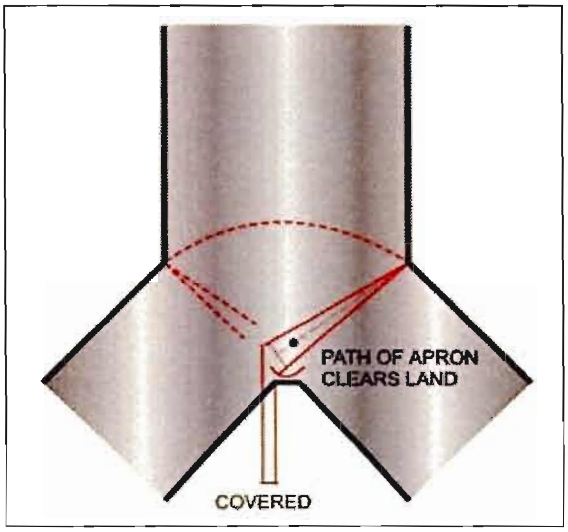


Figure 10: *Flopper gate diverting material to different receiving conveyors [11]*

1.3 RECURRING CHUTE PROBLEMS AND COUNTERMEASURES FROM INDUSTRY

Transfer chutes are a fundamental link when conveying ore and, therefore, it is important to get it right at the outset of design and fabrication. Design and fabrication issues can cause numerous problems when transferring material. Historically, conveyor system design focused on the system's overall structural integrity, while ensuring that the equipment would fit within the facility's constraints [13], [14], [15].

Little attention was given to design analysis or consideration for material flow characteristics. Normally the solution for controlling flow was to implement simple rock boxes [15]. This type of chute configuration is still commonly used in industry but with more emphasis on the flow of material. The most recurrent problems on transfer chutes are [13], [14]:

- Spillage
- Blocked chutes
- High wear on the receiving belt due to major differences between the material velocity and the belt velocity
- Rapid chute wear
- Degradation of the material being transferred
- Excessive generation of dust and noise
- Miss tracking of the receiving conveyor belt due to skew loading from the transfer chute.

Figure 11: *Chute liner degradation*

Figure 11 shows the excessive wear on ceramic tiles where the material trajectory from the feeding belt impacts the chute. These tiles are replaceable and a maintenance schedule normally specifies the replacement intervals. A problem arises when the frequency of these maintenance intervals is too high due to excessive wear on the liners.

Figure 12: *Results of continuous belt wear at transfer points*

The conveyor belt can account for up to 60% of the capital cost of a bulk materials handling plant. This means that the cost implications of constant replacement of a conveyor belt, due to wear, can become significantly higher than the original capital investment [16]. Figure 12 shows the extreme damage on a conveyor belt caused by abrasion and gouging.

Figure 13: *Dust from a transfer point onto a stockpile*

The presence of dust is an indisputable fact in many industries concerned with the handling or processing of products such as coal, mineral ores and many others [17]. As in the case of spillage, it is easy to identify transfer systems that cause dust clouds. Environmental regulations are in place to prevent excessive dust emissions.

Government organisations such as the Occupational Safety and Health Administration (OSHA), the Mine Safety and Health Administration (MSHA) and the National Institute for Occupational Safety and Health (NIOSH) closely monitor dust levels at all coal handling facilities [13]. Therefore, it is imperative that the chute design process caters for limiting dust emissions.

Systems normally used in industry are enclosed skirting systems, bag houses and dust collectors. This, however, is only treating the symptom rather than eliminating the primary cause. In order to minimise dust generation the use of low impact angles and minimal chute contact is required [14]. One of the most successful methods of controlling dust is atomised water spray systems using a combination of high pressure water and chemical substances.

Over the years, considerable research has gone into minimising wear on transfer chutes. There are currently a few different liner types to choose from, depending on the configuration and application of the chute. These include ceramic tiles; chrome carbide overlay materials and typical hardened steel plates such as VRN. A combination of liner materials can also be used, similar to the one shown in Figure 14.

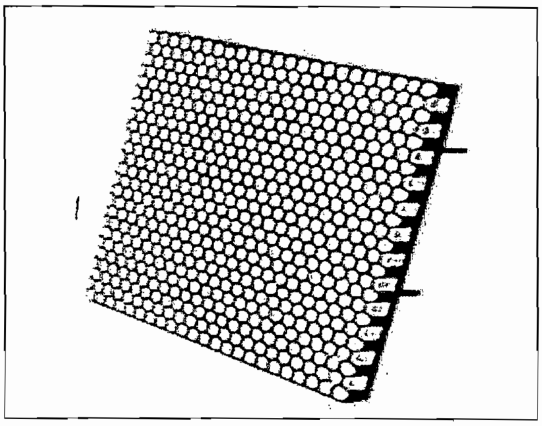


Figure 14: *Ceramic composite liners [18]*

This ceramic composite liner is an example of the new technology available in chute lining materials. It is a high wear resistant surface made from cylindrical alumina ceramic pellets bound within a resilient rubber base. The purpose of this material is to provide wear resistance through the use of ceramics while the rubber dampens the impact forces [18].

Some innovative concepts for chute design have been implemented since the materials handling industry started to incorporate new ideas. Benetech Inc. installed a new generation hood and spoon type chute at Dominion's 1200 MW Kincaid coal powered generating station as shown in Figure 15. This chute replaced the conventional dead box chute [19]. Their innovation is to use a pipe configuration combined with the hood and spoon concept.

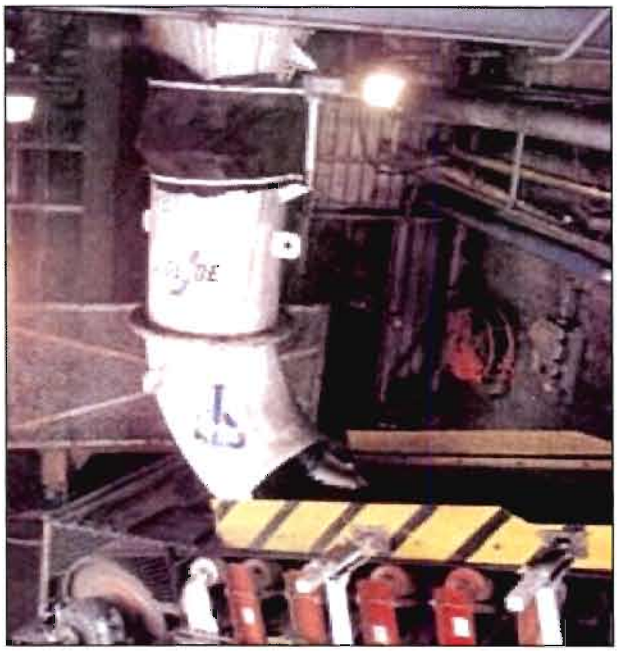


Figure 15: *Benetech Inteliflow J-Glide transfer chute [19]*

This chute has sufficient chute wall slope and cross sectional area to prevent material build-up and blocked chutes. Reduced collision forces in the chute minimize material degradation and the creation of excessive dust. The material velocity in the chute is controlled by the wall angles to obtain a discharge velocity with the same horizontal component as the belt velocity [19]. Figure 16 shows a flow simulation of the Benetech concept. The simulation shows that this concept will result in lower impact forces and reduce belt abrasion.

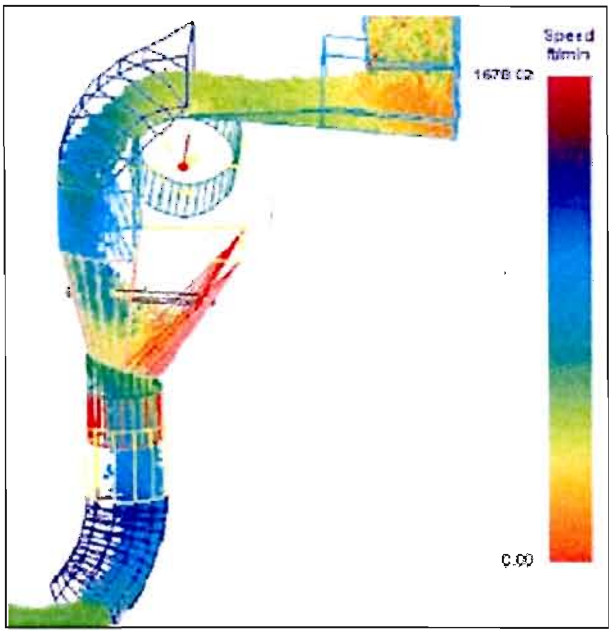


Figure 16: *Flow simulation of the Benetech Ineliflo chute [19]*

C.B.P. Engineering Corp. also considers the concept of pipe type sections to be the answer to most of the transfer chute problems. They describe it as a curved or half round chute. The modern perception is to gently guide the material in the required direction rather than use a square box design or deflector doors which turns or deflects the flow [20].

The industry is striving towards developing new technology in transfer chute design. One solution is to incorporate soft loading transfer chutes to alter the material flow direction with minimum impact on the side walls of chute and receiving conveyor. As experienced by many industries, these types of chutes can transfer material onto the receiving conveyor at almost the same velocity as the conveyor. By doing so, many of the problems with material transfer can be eliminated [13].

Most of these solutions, as proposed by industry, only address a few of the numerous problems experienced with transfer chutes. The dynamic hood and spoon chute appears to afford the best opportunity for solving most of the problems. There are still however many unanswered questions surrounding this design.

Figure 11 shows the installation of a hood type chute in the iron ore industry. It is clear from this image that liner wear in the higher impact areas is still an area of concern. Improvements can still be made to this design in order to further enhance its performance.

1.4 PURPOSE OF THIS RESEARCH

The bulk materials handling industry is constantly facing the challenge of implementing transfer chutes that satisfy all the system requirements. Problems such as high wear, spillage, blockages and the control of material flow are just some of the major challenges faced by the industry.

The objective of this research is to identify problems experienced with transfer chutes of an existing bulk handling system and to apply current design solutions in eliminating these problems. In doing so the research aims to introduce a new method of minimising liner wear caused by high impact velocities.

Dynamic chutes are discussed in particular where the entire design process addresses the problems identified on chutes in brown field projects. Approaching chute design from a maintenance point of view, with the focus on reducing liner degradation, will provide a fresh approach to transfer chute design. The concepts discussed in this dissertation, (dynamic and dead box chutes), are commonly used in industry. However, some research is done to determine whether a combination of these concepts can solve some of the problems experienced by industry.

At the hand of all the information provided in this dissertation its purpose is to enable the chute designers to better understand the process of chute optimisation and design. This is achieved through the discussion of a case study where the chutes are evaluated and re-designed to achieve the desired performance.

1.5 SYNOPSIS OF THIS DISSERTATION

Chapter 1 gives an introduction to the bulk materials industry and the role that transfer chutes plays in this industry. Some of the problems that the industries have been experiencing with transfer chutes were identified and the diverse solutions to these problems discussed. These solutions were reviewed to identify whether improvement would be possible.

Chapter 2 provides a better understanding of the functionality and the conceptualisation of transfer chutes as well as investigating the theory behind material flow through transfer chutes. This theory reviews the research and design objectives used as a guideline when approaching a new chute configuration. The guidelines for evaluating and designing transfer chutes are used to verify the performance of these chutes in the iron ore industry.

Chapter 3 identifies some practical problems experienced on transfer chutes at an existing bulk transfer facility. These problems are identified through a series of tests where the actual flow inside the chutes is monitored via CCTV cameras. The results obtained from these tests are specific to this facility but can provide insight into the cause of some problems generally experienced in the industry. These results can provide helpful information when modifying or re-designing new transfer chutes.

Chapter 4 uses the theory discussed in Chapter 2 to conceptualise a new transfer chute configuration for the transfer points that were tested. All the facility constraints are taken into account during the process in order to obtain an optimum solution to the problems identified during the chute test work. The old chutes did not have major problems with liner wear due to large dead boxes. However, this remains a serious consideration for the new dynamic chute design due to its configuration where there is continuous sliding abrasion of the chute surface. A new concept for the reduction of liner degradation is introduced in this chapter.

Before manufacturing and installing this new concept, it is important to verify that it will perform according to conceptual design. Chapter 5 is a discussion on the use of the Discrete Element Method as a verification tool. A simulation of the new transfer chute concept is done to visualise the behaviour of the material as it passes through the new transfer chute configuration.

Chapter 6 discusses the benefits of the new transfer chute configuration. A conclusion is made as to what the financial implications will be with the implementation of this new concept. Recommendations are made for future studies in the field of bulk materials handling. These recommendations focus on the optimisation of processes and the reduction of maintenance cost to the facility.

CHAPTER 2: BASIC CONSIDERATIONS IN CHUTE DESIGN

2.1 PREFACE

In an economic driven world the pressure for production is often the cause of the loss of production. This is a bold statement and is more factual than what the industry would like to admit. This is also valid in the bulk materials handling industry. Production targets seldom allow time for investigation into the root cause of the problems. The quick fix option is often adopted, but is frequently the cause of even more maintenance stoppages.

Existing chutes on brown field projects often fail due to an initial disregard for the design criteria, changes in the system parameters or lack of maintenance. These transfer points are often repaired on site by adding or removing platework and ignoring the secondary functions of a transfer chute. Therefore, it is imperative to always consider the basic chute specifications when addressing a material transfer problem [21].

2.2 DESIGN OBJECTIVES

In the quest to improve or design any transfer point, some ground rules must be set. This can be seen as a check list when evaluating an existing chute or designing a new chute. Transfer chutes should aim to meet the following requirements as far as possible [21], [22], [23]:

- Ensure that the required capacity can be obtained with no risk of blockage
- Eliminate spillage
- Minimise wear on all components and provide the optimal value life cycle solution
- Minimise degradation of material and generation of excessive dust
- Accommodate and transfer primary and secondary scraper dribblings onto the receiving conveyor

- Ensure that any differences between the flow of fine and coarse grades are catered for.
- Transfer material onto the receiving conveyor so that at the feed point onto the conveyor:
  - the component of the material flow (parallel to the receiving conveyor) is as close as possible to the belt velocity (at least within 10%), to minimise the power required to accelerate the material and to minimise abrasive wear of the belt
  - the vertical velocity component of the material flow is as low as possible so as to minimise wear and damage to the belt, as well as to minimise spillage due to material bouncing off the belt
  - The flow is centralised on the belt and the lateral flow is minimised so as not to affect belt tracking and avoid spillage.

With the design of a new chute there are up to 46 different design inputs with 19 of these being absolutely critical to the success of the design. Some of the most critical preliminary design considerations are shown in Table 1 [24].

Table 1: *Design Input Reference Requirements [24]*

Aria	**Unit**
Feed Conveyor	
Belt Speed	m/s
Belt Width	mm
Jib/Head Pulley Dia	mm
Pulley Width	mm
Angle to Horizontal at the Head Pulley	degrees
Belt Troughing Angle	degrees
Sight Height Data	
Feed Conveyor Top of Belt to Roof	mm
Drop Height	mm
Receiving Conveyor Top of Belt to Floor	mm
Receiving Conveyor	
Belt Speed	m/s
Belt Width	mm
Belt Thickness	mm
Angle of Intersection	degrees
Angle to Horizontal	degrees
Belt Troughing Angle	degrees
Material Properties	
Max. Oversize Lump (on top)	mm
Max. Oversize Lump (on top)	degrees

Studies done by Jenike and Johanson Inc. have identified six design principles that can serve as a guideline in chute optimisation exercises. These six principles focus on the accelerated flow in the chute which they identified as the most critical mode [25].

Within accelerated flow the six problem areas identified by Jenike and Johanson Inc. are [25]:

- plugging of chutes at the impact points
- insufficient cross sectional area
- uncontrolled flow of material
- excessive wear on chute surfaces
- excessive generation of dust
- attrition or breakdown of particles.

2.2.1 *Plugging of chutes*

In order to prevent plugging inside the chute, the sliding surface inside the chute must be sufficiently smooth to allow the material to slide and to clean off the most frictional bulk solid that it handles. This philosophy is particularly important where the material impacts on a sliding surface. Where material is prone to stick to a surface, the sliding angle increases proportionally to the force with which it impacts the sliding surface. In order to minimise material velocities and excessive wear, the sliding surface angle should not be steeper than required [25].

2.2.2 *Insufficient cross sectional area*

The cross section of the stream of material inside the chute is a function of the velocity of flow. Therefore, it is critical to be able to calculate the velocity of the stream of material particles at any point in the chute. From industry experience a good rule of thumb is that the cross section of the chute should have at least two thirds of its cross section open at the lowest material velocity [25]. When the material is at its lowest velocity it takes up a larger cross section of chute than at higher velocities. Therefore, this cross section is used as a reference.

2.2.3 *Uncontrolled flow of material*

Due to free falling material with high velocities, excessive wear on chutes and conveyor belt surfaces are inevitable. Therefore, it is more advantageous to have the particles impact the hood as soon as possible, with a small impact angle after discharge from the conveyor. With the material flowing against the sloped chute walls, instead of free falling, the material velocity can be controlled more carefully through the chute [25].

2.2.4 *Excessive wear on chute surfaces*

Free flowing abrasive materials do not normally present a large wear problem. The easiest solution to this problem is to introduce rock boxes to facilitate material on material flow. Chute surfaces that are subjected to fast flowing, sticky and abrasive materials, are the most difficult to design.

A solution to this problem is to keep the impact pressure on the chute surface as low as possible. This is done by designing the chute profile to follow the material trajectory path as closely as possible. By doing so the material is less prone to stick to the chute surface and the material velocity will keep the chute surface clean [25].

2.2.5 *Excessive generation of dust*

Material flowing inside a transfer chute causes turbulence in the air and excessive dust is created. In order to minimise the amount of dust, the stream of material must be kept in contact with the chute surface as far as possible. The material stream must be compact and all impact angles against the chute walls must be minimised. A compact stream of material means that the material particles are flowing tightly together. At the chute discharge point the material velocity must be as close as possible to the velocity of the receiving belt [25].

2.2.6 *Attrition or breakdown of particles*

The break up of particles is more likely to occur when large impact forces are experienced inside a chute than on smooth sliding surfaces. Therefore, in most cases, the attrition of material particles can be minimised by considering the following guidelines when designing a transfer chute: minimise the material impact angles, concentrate the stream of material, keep the material stream in contact with the chute surface and keep the material velocity constant as far as possible [25].

2.3 INTEGRATING A MORE APPROPRIATE CHUTE LAYOUT WITH THE PLANT CONSTRAINTS

According to Tunra Bulk Solids in Australia, the process for design and commissioning of a new plant basically consists of four steps. The entire process is based on understanding the properties of the material to be handled. [1]

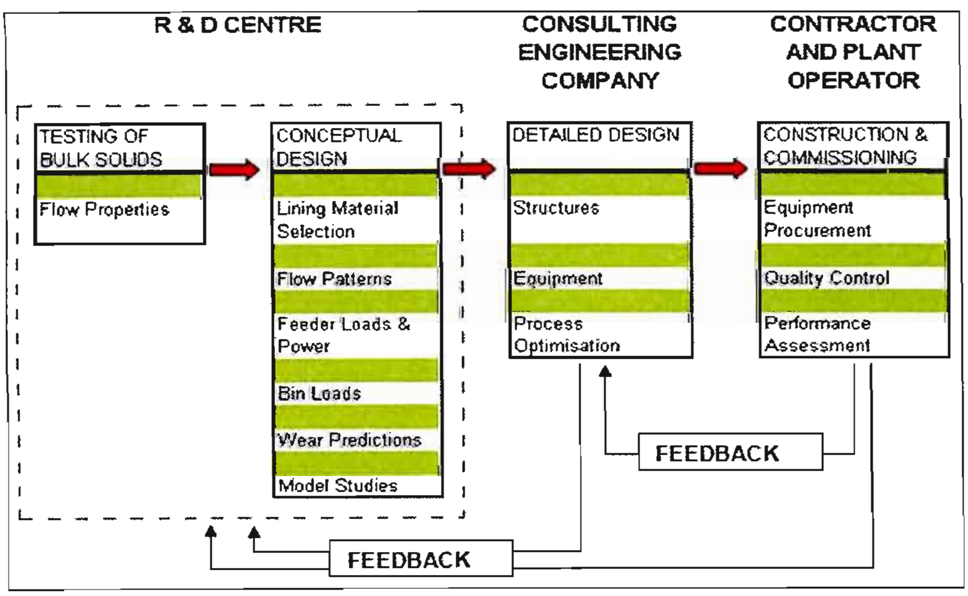


Figure 17: *Four step process for plant design and commissioning [1]*

Figure 17 illustrates this four step process. These steps are a good guideline in order to incorporate a more appropriate chute layout for the plant constraints. This is an iterative process where all the possible solutions to a problem are measured against all the possible plant constraints. This section focuses more on the second column of Figure 17 and specifically on structures and equipment. During this stage of design the utilisation of 3D parametric modelling also creates an intimate and very accurate communication between the designer and the project engineer or client. This effective communication tool will save time and improve the engineering process [24].

A good example of obtaining an appropriate chute layout for the plant constraints can be explained as follows. On an existing plant, a transfer point will have a specific transfer height from the top of the feed conveyor to the top of the receiving conveyor. If the feed conveyor has an incline section, to obtain the required transfer height, it will also have a curve in the vertical plane of that incline section. This curve has a certain minimum radius in order to keep the belt on the idlers at high belt tensions [26].

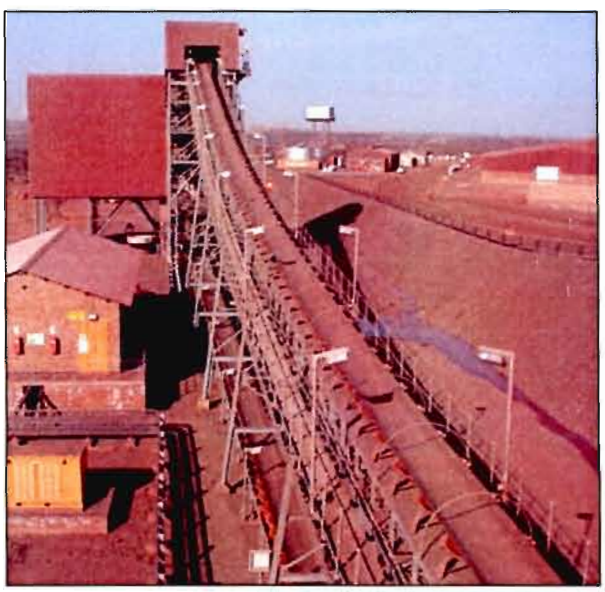


Figure 18: *Vertical curve on incline conveyor*

If the transfer height at a transfer point is changed, the path of the feeding conveyor should always be taken into consideration. With an increase in transfer height, the vertical curve radius will increase as well in order to prevent the conveyor from lifting off the idlers in the curve. This will require expensive modifications to conveyor structures and, therefore, in most cases be a pointless exercise. Figure 18 shows clearly the large radius required to obtain a vertical curve in a belt conveyor.

Other considerations on brown field projects might be lift off of the receiving conveyor at start up, before or after the vertical curve. This is caused by peaks in belt tension at start up which may cause the belt to lift off the idlers and chafe against the chute. In some cases this can be solved by fitting a roller, as shown in Figure 19, to the underside of the chute to protect it from being damaged by the belt or to protect the belt from being damaged by the chute. The position of this specific chute is just after a vertical curve where the belt tends to lift off at start up.

Figure 19: *Protective roller on a transfer chute*

2.4 INVESTIGATING THE CORRECT CHUTE PROFILE FOR REDUCED LINER WEAR

In order to reduce chute wear, the curved-profile variable chute concept is introduced [27]. This concept was originally developed by Professor Roberts for the grain industry in 1969 [28]. After many years of research and investigation, CMR Engineers and Project managers (Pty) Ltd., came to the following conclusion: any improvement in coal degradation, dust generation and chute wear can only be achieved by avoiding high impact forces or reducing them as much as possible [27].

At any impact point of material in a chute or conveyor, kinetic energy is dissipated. This increases material degradation and wear on liners and conveyor belt covers. Therefore, it is good practise to redirect the kinetic energy in a useful manner. This action will help to reduce liner and belt wear [32].

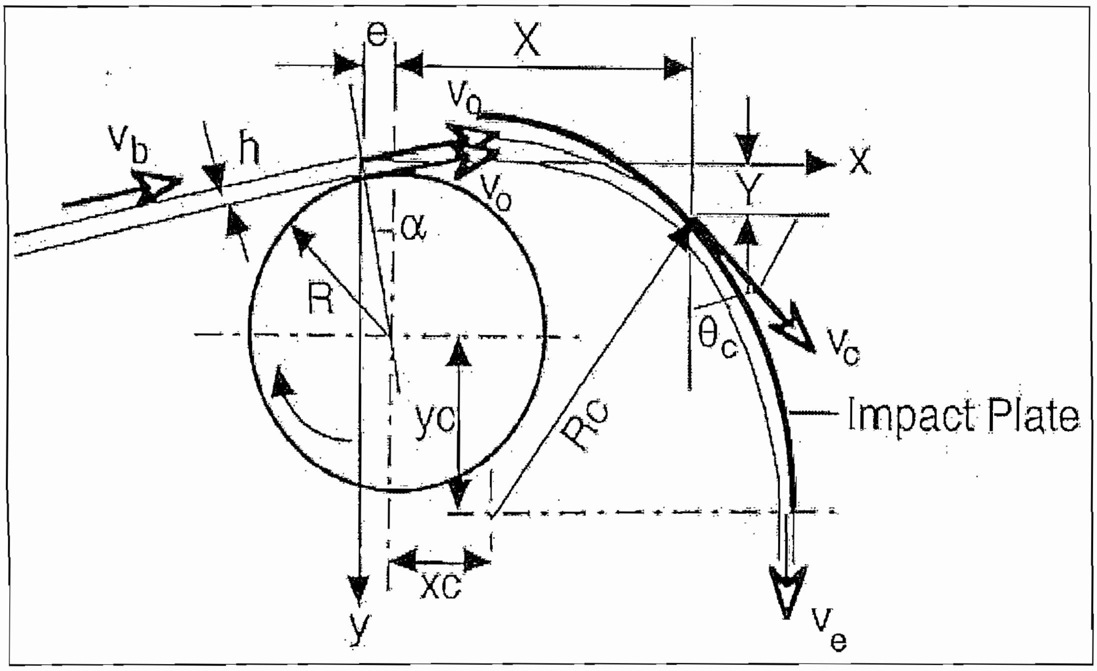


Figure 20: *Geometry of the impact plate and material trajectory [30]*

The path followed by the material discharged over the end pulley of a belt conveyor is known as its trajectory and is a function of the discharge velocity of the material from the conveyor [29]. Figure 20 shows the material trajectory as well as the radius and location of the impact plate. In the case of dynamic chutes this impact plate represents the back plate of the chute.

The correct chute profile to reduce wear must cater for the proper location of the chute covers and wearing plates. This location depends upon the path of the trajectory which must be predicted as accurately as possible.

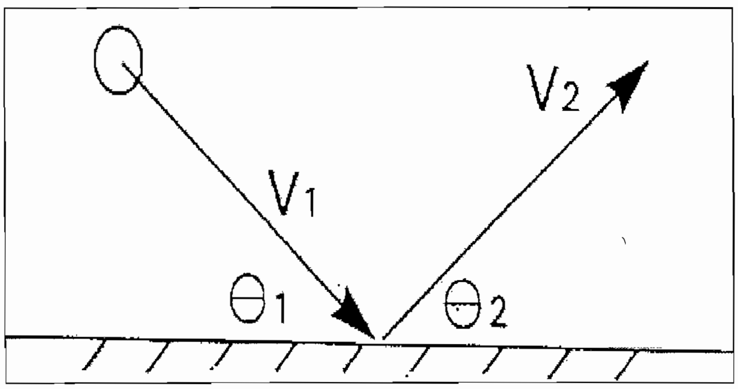


Figure 21: *Model for the impact of a particle on a flat surface [29]*

Figure 21 illustrates a material particle impinging on a flat chute surface at an angle of approach θ_1, and with approach velocity V_1. This particle will then rebound off the chute plate at an angel θ_2, and velocity V_2. The wear on the chute liners, or the surface, shown in Figure 21, will be a function of the vector change in momentum of the particle. One component will be normal to and the other component parallel to the flat surface. The parallel component is referred to as the scouring component along the surface. [29].

It is important to determine the radius of curvature of material within the trajectory. It is now a simple exercise to determine the chute hood radius depending on plant constraints. Firstly the material trajectory must be calculated.

According to the mechanical handling engineers association in Perth, Australia, it is beneficial to keep the impact angle as small as possible. Impact angle less than 20° are recommended for most liner materials. This will ensure an acceptably small impulse force component normal to the surface. The rate at which the material is gouging away the chute liner at the impact point will be reduced [29].

The material trajectory is determined by equation 1:

$$y = x^2\left(\frac{g}{2v^2(\cos(\alpha))^2}\right) - x\tan(\alpha) \tag{1}$$

Where the origin of the x and y axis is taken at the mean material height, h, and the discharge point on the pulley as shown in Figure 20. The variables involved in the calculation of the material trajectory are [30]:

y = vertical position on the grid where the trajectory is determined
x = position parallel to the receiving belt line where the trajectory is determined
v = material speed
g = gravitational constant
α = inclination angle of the feeding conveyor

After the material leaves the belt, a simplified assumption can be made that it falls under gravity. It is quite clear that in order to minimise the impact angle, the impact plate must follow the path of the material trajectory as far as possible. It will almost never be possible to obtain a contact point between the material and the chute where there is a smooth contact with no impact angle.

This radius of curvature of the material trajectory is determined as follows [30]:

$$R_c = \frac{[1+(\frac{gx}{v\cos\theta})]^{1.5}}{\frac{g}{v\cos\theta}} \quad (2)$$

Where:

g = gravitational constant

v = material speed

θ = Angle at discharge

In order to simplify the manufacturing process of a curved chute, the radius must be constant. For a relatively smooth contact between the material and the chute plate, the radius of the curved chute, at the point of contact, is as close as possible to the material discharge curvature radius [30]. This is rarely possible on brown field projects due to facility constraints. In this case there will be higher probability for rapid liner wear. Each situation must be individually assessed to determine the best solution.

Cross sectional dimensions of the transfer chute must be sufficient to collect the material and ensure continuous flow without causing blockages. At the same time, the chute profile must not result in excessive material speed. Material speed inside the chute will be considered to be excessive when it can not be controlled to exit the chute at approximately the same velocity to that of the receiving conveyor. Chutes may block for the following reasons [29]:

- Mechanical bridging due to large lumps locking into one another
- Insufficient cross section causing cohesive material to choke or bridge
- Inadequate chute inclination causing fines build-up
- Corner effects or cohesion causing material to stick to the chute walls.

For the handling of large lumps of material, field experience has shown that the chute cross sectional area should be 2.5 times the major dimension of the largest lumps. To avoid possible bridging of the material in the chute, the recommendation is to make the inner chute volume as large as possible. This will be guided by the support steelwork around the transfer point [29].

Field experience has shown that it is advisable, depending on the material being transferred, that the chute inclination angles be no less than 65° to 70°. Corner effects should also be avoided where material gets stuck in the inner corners of chute plate work. These angles should preferably be no less than 70°.

2.5 FEED CHUTE GEOMETRY FOR REDUCED BELT WEAR

The design parameters to reduce both chute and belt wear are interrelated. Research done at the Phalaborwa copper mine is a good case study to prove the concept of a curved chute profile. This mine had specific problems with high belt wear at transfer points. At this facility an in-pit 60 x 89 gyratory crusher and incline tunnel conveyor was commissioned to haul primary crushed ore. A conventional dead box chute transfers ore from the crusher to a 1800 mm wide incline conveyor [31].

The maximum lump size handled by this section of the facility is 600 mm (60 kg). An 18 mm thick top cover was specified for this conveyor with an 'X' grade rubber according to DIN (abrasion value < 100 mm). This belt had an original warranty of 10 years. After 3.5 years, the top cover started to show signs of excessive wear and the tensile cords of the 18 mm thick cover were visible [31].

In April 1994, Phalaborwa commissioned the curved chute concept and a new belt on the incline conveyor. Six months after commissioning, no gouging or pitting damage was evident. The material velocity through this curved chute onto the incline conveyor is shown in Figure 22 [31].

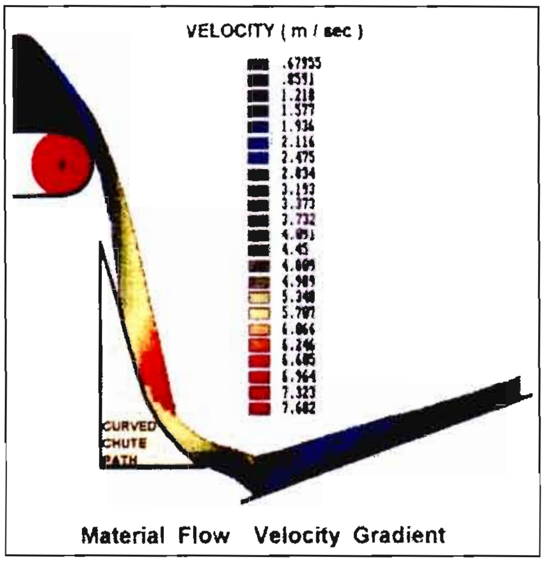


Figure 22: *Ore flow path in the curved chute onto the incline conveyor [31]*

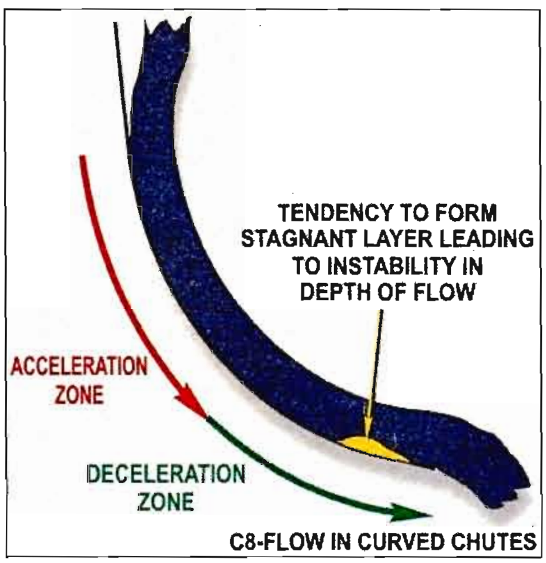


Figure 23: *Gentle deceleration of the product before impact on the receiving belt [32]*

Figure 23 illustrates the gentle deceleration of material that is achieved with the curved chute concept. This helps to reduce belt wear because it is relatively easy to discharge the material at the same velocity as the receiving conveyor.

The material speed, v, can be calculated at any point in the chute using equation 3 and equation 4 [33]:

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

This equation is only applicable if the curved section of the chute has a constant radius R and μ_e is assumed constant at an average value for the stream [33].

μ_e = friction coefficient
θ = angle between the horizontal and the section of the spoon where the velocity is determined and

$$K = v_0^2 - \frac{6\mu_e gR}{1 + 4\mu_e^2} \tag{4}$$

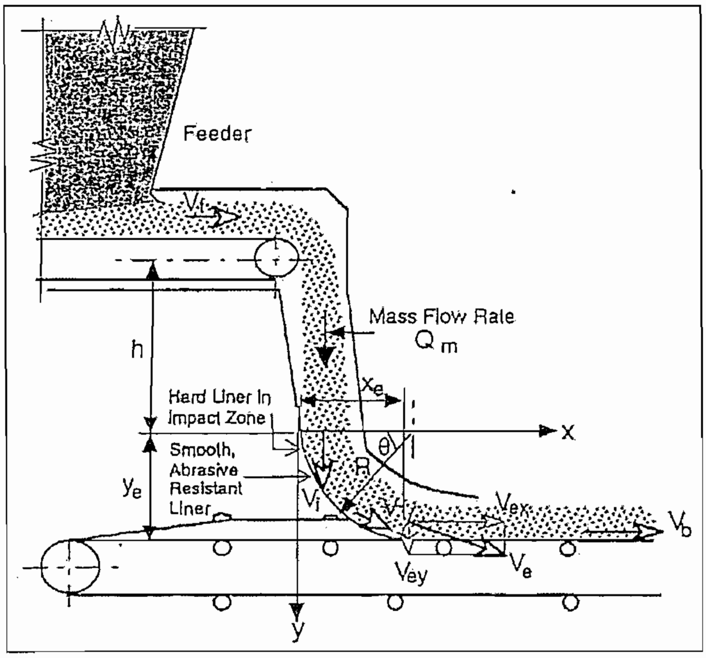


Figure 24: *Typical feed chute discharge model [33]*

The velocity V_e, at the discharge of the chute, can be determined from equation 3 and equation 4. The components, V_{ey} and V_{ex} of the discharge velocity, as shown in Figure 24, can now be calculated. This investigation should aid the optimisation of the chute profile in order to [33]:

- match the horisontal component V_{ex}, of the material exit velocity, as close as possible to the belt speed
- reduce the vertical component V_{ey}, of the material exit velocity, in order to minimize abrasive wear on the receiving conveyor.

2.6 CONCLUSION

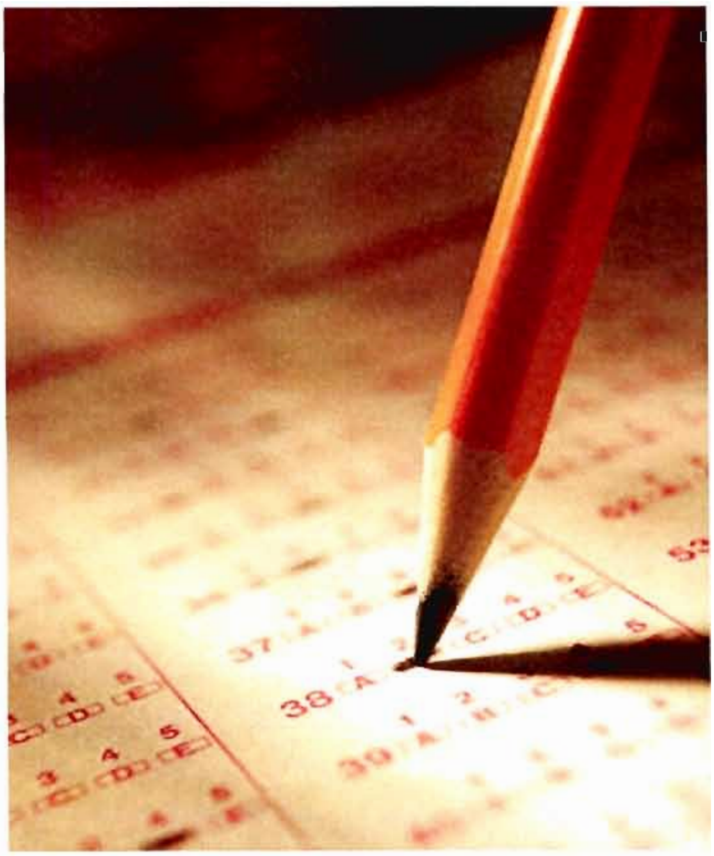
This section discussed the technical background necessary for the optimisation of transfer chutes, on an existing iron ore plant, which will be discussed in Chapter 4. The focus is specifically aimed at reducing impact wear on chute liner materials and abrasive wear on receiving conveyor belts. Important to note from this section is the acceptable limits of dynamic chute optimisation or design. These limits are:

- a material impact angle of less than 20°
- a variance of less than 10% between the receiving belt velocity and the material discharge velocity component parallel to the receiving conveyor.

An important aspect of chute optimisation is to consider the facility constraints. These constraints are in some cases flexible, but in most cases the chute optimisation process must be designed within these constraints. This means that any new concept will have to be measured against what is possible within the facility limits.

It is important to note that only the most common transfer chute problems were mentioned in this chapter. Other possible problems were not addressed in this chapter as it is normally related to detail design issues. Solutions to these problems are unique to each type of chute and will be addressed for the specific case study in Chapter 4.

CHAPTER 3: TESTS FOR THE IDENTIFICATION OF RECURRING PROBLEMS ON EXISTING CHUTES



3.1 PREFACE

Since the completion of a certain iron ore handling facility, it has been experiencing recurring material transfer problems at high capacities. In order to investigate the problem, it was decided that performance testing of the chutes should be carried out. The purpose of these tests was to monitor chute performance at transfer rates of up to the design capacity of 10 000 t/h for various grades of iron ore handled by the facility. Some of the methodologies used in testing are only applicable to this specific facility.

Due to variations and surges associated with the reclaim operations at the facility, performance testing focused on reclaim side chutes. This means that all the transfer points at the exit points of the stockyard conveyors were tested. Nineteen tests were conducted on various stockyard transfers. Information such as the specific facility or conveyor numbers cannot be disclosed due to the confidentiality of information.

To analyse SCADA data, the stacker reclaimer scale is used to determine the peak surges passing through the transfer under investigation. The reason for this is that the peaks in flow, due to reclaiming operations, flatten out when passing through the transfer points. This is due to chute throat limitations and small variations in belt speeds. If the down stream scales are used it would give an inaccurate indication of the amount of ore that passed through the transfer chute.

3.2 TEST METHODOLOGY

A CCTV camera was installed in a strategic position inside the head chute of the stockyard conveyors. These cameras provided valuable information on the physical behaviour of the material flow inside the transfer chutes. Where possible, cameras were also placed on the receiving belt in front of and behind the chute. This was done to monitor belt tracking and spillage. A high frequency radio link between the head chute and the control tower made it possible to monitor the cameras at all times.

SCADA data was used to determine and establish the condition of the material transfer at the time of the test. Data from various scales en route were obtained as well as confirmation of blocked chute signals. In analysing the SCADA data, the stacker reclaimer scale is used to determine the peak surges passing through the transfer being tested.

Data was recorded from a sampling plant at the facility. This data provides the actual characteristics of representative samples taken and analysed by the sampling plant during the duration of the test. The data gathered consist of moisture content of the material sample as well as the size distribution of the ore.

Where possible, an inspector was placed at the transfer point being tested to observe and record the performance. The inspector had a two way radio for communication with the test co-ordinator in the central control room. He would also be responsible for the monitoring of any spillage, dust emissions etc. that may not be picked up by the cameras.

Prior to commencing a test on a specific conveyor route, the following checks had to be performed on all the material conveying equipment:

- Clean out all transfer chutes and remove any material build-up from the side walls
- Check that feed skirts are properly in position on the belt
- Check that the conveyor belt is tracking properly at no load
- Check conveyor idlers are all in position and free to rotate
- Check blocked chute detectors are operational and in the correct location

- Change the position of the blocked chute detector if required to improve its function
- Test and confirm that the CCTV systems are functioning correctly
- Assign persons with 2 way radios and cameras to monitor and record the results at each transfer point on the route.

3.3 CHUTE PERFORMANCE ACCEPTANCE CRITERIA

A material transfer chute performs to specification if it transfers a maximum of 10 000 t/h of a specific iron ore grade without experiencing any of the following problems:

- Material build up inside the chute or blocking the chute, i.e. material is not exiting the chute at the same rate as it is entering
- Material spillage encountered from the top of the transfer chute
- Material spillage encountered where material is loaded onto the receiving conveyor
- Belt tracking of the receiving conveyor is significantly displaced by the loading of material from the transfer chute onto the conveyor.

Tests were conducted over a period of one month and in such a short period visible wear is difficult to quantify. Due to the sensitivity of the information no historical data in terms of chute or belt wear were made available by the facility. Therefore it is not part of the criteria for these specific tests. Should a chute however fail to perform according to the set criteria it validates the need for modifications or new designs.

3.4 DISCUSSION OF PROBLEM AREAS

The major concern during the test work is material flow at the transfer points. Secondary concerns are spillage, tracking of the receiving belt and material loading onto the receiving belt. One of the external factors that play a significant role in material flow rate is the method and process of reclaiming. This section will highlight all the problem areas observed during the test work.

Figure 25 shows the layout of the stockyard area. This layout will serve as a reference when the specific test results at each transfer point are discussed. The legends for Figure 25 are as follows.

 Transfer points where performance tests have been done

 Direction that the conveyors are moving in

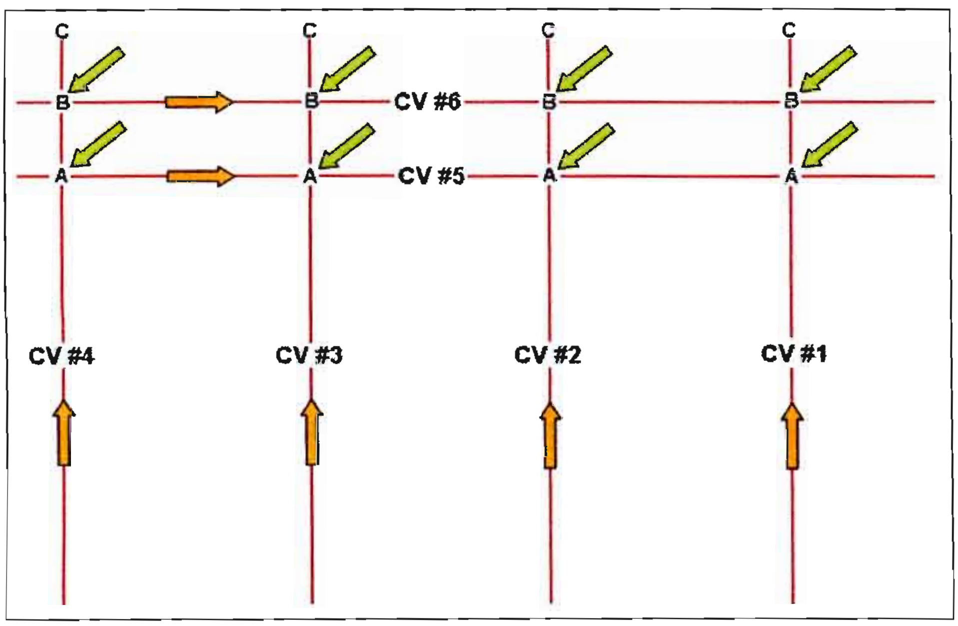


Figure 25: *Layout of conveyors for chute test work*

All four stockyard conveyors have a moving head arrangement. This means that the chutes are split up into two sections. A moving head discharges material onto either conveyor (CV) #5 or CV #6 via a static transfer chute. The moving head positions are shown by A, B and C in Figure 25.

Position C is the purging or dump position. This position is used when the stacker reclaimer is in stacking mode and any material left on the stockyard conveyor gets dumped. The material does not end up on the stockpiles, preventing contamination.

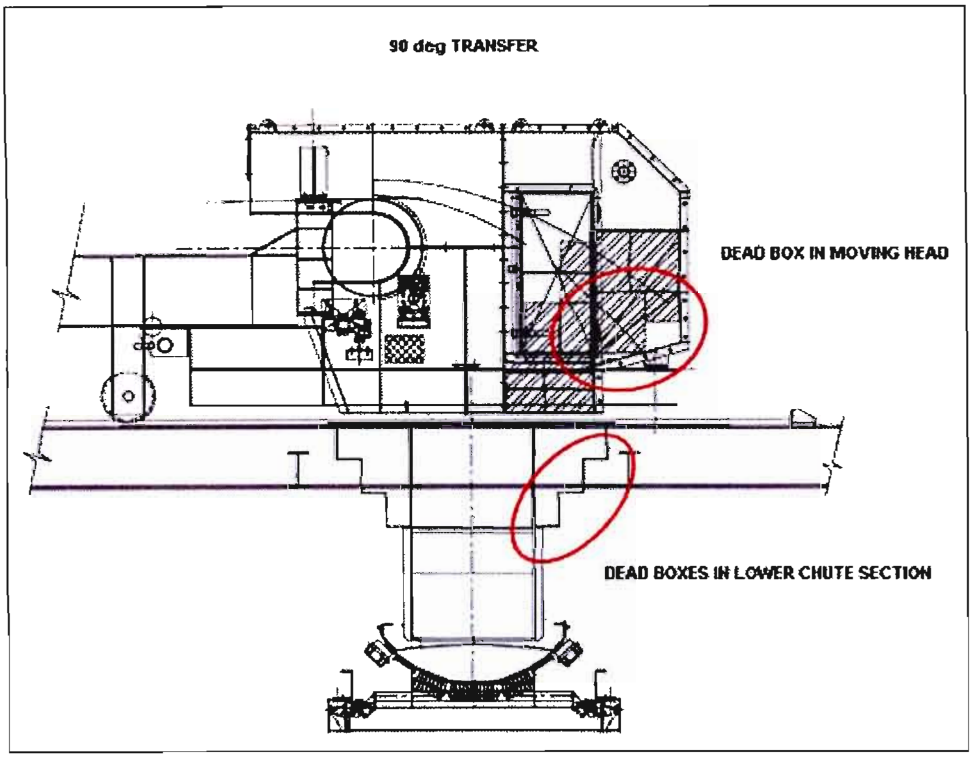


Figure 26: *Configuration of the existing transfer chute*

Figure 26 shows the configuration of the existing transfer chutes. These chutes capture the trajectory from the head pulley in a dead box situated in the top part of the chute. The material then cascades down a series of smaller dead boxes onto the receiving conveyor below.

Various grades of iron ore were tested during the testing period. These different grades of iron ore are shown in Table 2. Three fine grades and four coarse grades were used. The coarse material is defined as particles with a diameter of between 12 mm and 34 mm and the fine material with diameters of between 4 mm and 12 mm.

Table 2: *Iron ore grades used for chute test work*

Material	Predominant Lump Size
Fine K	5 mm
Fine N	8 mm
Fine A	8 mm
Coarse K	25 mm
Coarse D	34 mm
Coarse S	12 mm
Coarse A	20 mm

The CCTV cameras were placed inside the moving head pointing down into the static chute overlooking the receiving conveyor. Figure 27 shows the camera angle used during testing. This is a view of a clear chute before testing. The legends for clarification of all the video images are as follows:

Front of the chute throat opening

Top of flowing material at the chute throat opening

Flow pattern of the material

Direction of the receiving belt

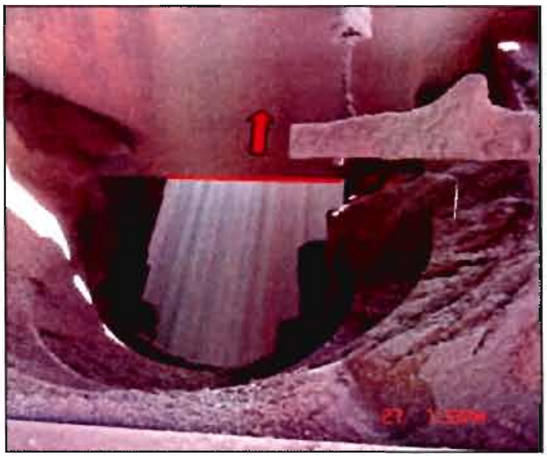


Figure 27: *Clear chute indicating camera angle*

3.4.1 *Coarse Material vs. Fine Material*

Differences in transfer rates between coarse material and fine material are evident from the data gathered during the test programme. These results are discussed later in this chapter. The area between the yellow arrows and the red line is the amount of 'freeboard' available. Freeboard is the open space available between the top of the flowing stream of material and the chute plate work. Figure 28 and Figure 29 shows the flow of coarse ore and fine ore respectively in the same chute at 8 000 t/h.

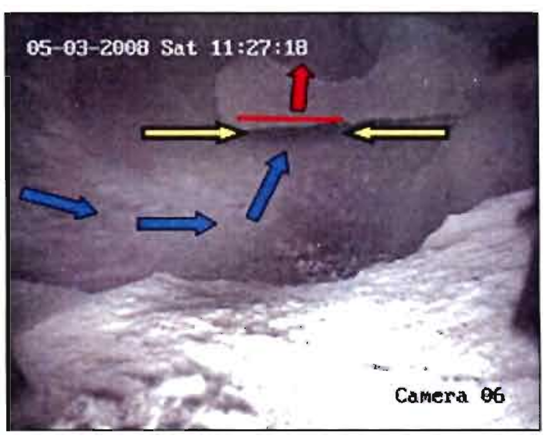


Figure 28: *Coarse material at 8 000 t/h*

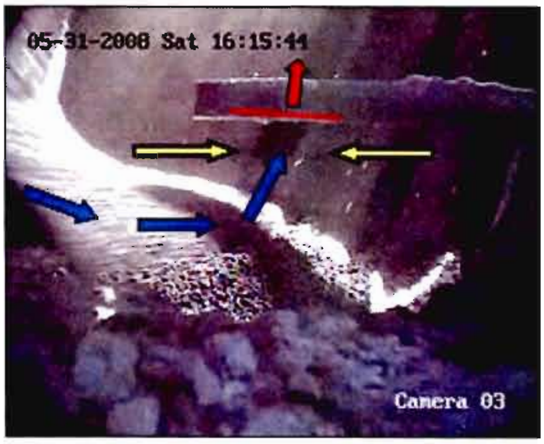


Figure 29: *Fine material at 8 000 t/h*

The amount of 'freeboard' with fine material is much larger than with coarse material. It is, therefore, obvious that coarse material is more likely to block a chute when peak surges occur. This is due to particles that interlock in the small discharge opening of the chute.

Figure 30: *Blocked chute with coarse material at 8 600 t/h*

Figure 30 is a snap shot of a chute blocked with coarse ore due to the material interlocking at the discharge opening. The time from material free flowing to a blocked chute signal was approximately 10 seconds. This is determined by comparing the CCTV camera time to the blocked signal time on the SCADA.

The high clay content in finer material can also cause problems in the long run. When wet fines are fed through the chutes a thin layer of fines builds up and sticks to the sides of the chute. As this layer dries out it forms a new chute liner and the next layer builds up. This process occurs gradually and will eventually cause the chute to block.

3.4.2 *Cross Sectional Area*

Video images of a blocked chute on the receiving belts were analysed to determine whether the blockage was caused by material build up on the belt underneath the chute. This indicated that with the occurrence of a blocked chute the material keeps flowing out of the chute at a constant rate without build up. From this the assumption can be made that, in the case of a blocked chute, the material enters the chute at a higher rate than it is discharged at the bottom. Therefore, the conclusion can be made that the chute cross sectional area at the discharge is insufficient to handle the volume of ore at high throughput rates.

Tests with a certain type of coarse material yielded a very low flow rate requiring adjustment to the chute choke plate on the transfer between CV #3 and CV #5. The chute choke plate is basically a sliding door at the bottom of the chute to adjust the discharge flow of material. Tests with another type of coarse material, shown in the summary of test results, indicates how the choke plate adjustment can increase the throughput of material in the chute.

Data of all the different types of ore at the facility are obtained at the sampling building. This data shows that the material size distribution for the two types of coarse material, used in the tests mentioned above, are the same. This indicates that the test results with the second coarse material are an accurate reflection of what will be experienced with the first type of coarse material. Special care should be taken when adjusting the choke plate to make sure that skew loading is not induced by the modification.

3.4.3 *Spillage*

During one of the first tests on the transfer between CV #2 and CV #6, spillage was observed at one of the side skirts on the receiving belt. A piece of the side skirt had been damaged and pushed off the belt as shown by Figure 31. This caused some of the material to be pushed off the belt when skew loading from the chute caused the belt to miss track. In this case, spillage was not caused by the skirt but by skew loading from the chute onto the receiving conveyor.

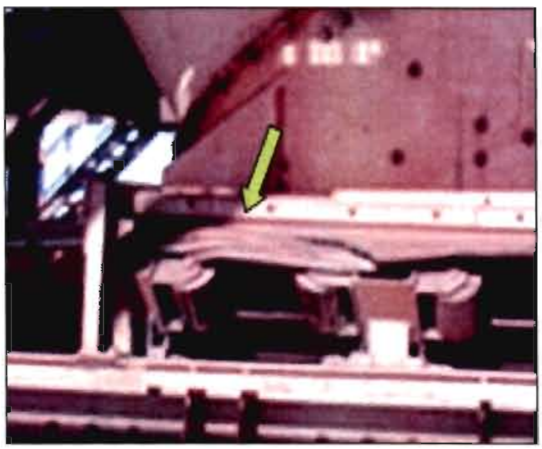


Figure 31: *Damaged side skirt*

A greater concern is spillage on the moving head chute of CV #3 and CV #4 loading onto CV #6. It appears as if the head chute creeps during material transfer onto CV #6. As the chute creeps, the horizontal gap between the moving head chute and the transfer chute reaches approximately 180 mm. Facility operations proposed a temporary solution by moving the head chute to the dumping or purging position and back to CV #5 before stopping over CV #6. The reason for this creep could be attributed to slack in the moving head winch cable.

3.4.5 *Belt Tracking and Material Loading*

The only belt tracking and material loading problems observed occurred on the transfer between CV #2 and CV #5 / CV #6. A diverter plate was installed at the bottom of the chute in order to force material flow onto the centre of the receiving conveyor belt. This plate now causes material to fall to the left of the receiving belt causing the belt to track to the right.

Figure 32: *View behind the chute of the receiving conveyor before loading*

Figure 32 shows the view from a CCTV camera placed over the receiving conveyor behind the chute. Note the amount of the idler roller that is visible before loading.

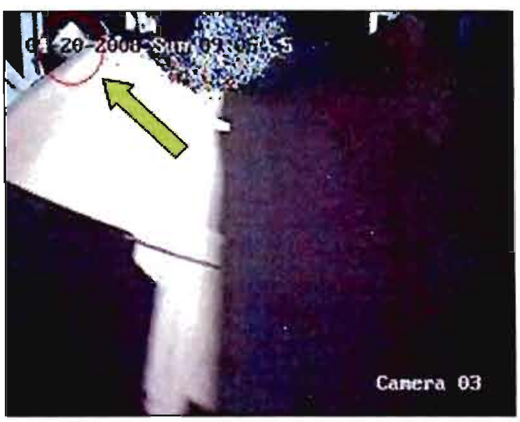


Figure 33: *View behind the chute of the receiving conveyor during loading*

Figure 33 shows the view from a CCTV camera placed over the receiving conveyor behind the chute during loading. Note the difference between the amount of the idler roller that is visible between Figure 33 and Figure 32. This is a clear indication of off centre belt tracking due to skew loading.

At the same transfer point it appears as if the configuration of the chute causes the material to be dropped directly onto the receiving belt from the dead box in the moving head. This will cause high impact wear on the belt in the long run. High maintenance frequencies will be required on the impact rollers underneath the chute and the roller bearings will have to be replaced frequently.

3.4.6 *Reclaiming Operations*

Reclaim operations are done from the stacker reclaimer that scoops up the material with a bucket wheel from the stockpile. The machine starts at the top bench of the stockpile and reclaims sideways until it is through the stockpile. This sideways movement is repeated while the machine moves down the stockpile. If the machine digs too deep into the stockpile small avalanches can occur that over fill the buckets. This causes peak surges in the flow on the conveyor system.

With an increase in the peak digging or reclaim rate, as requested for test work, it seemed that the peak surges increased as well. In normal reclaiming operations (average reclaim rate of 6 000 t/h to 7 000 t/h) the peaks in reclaim surges do not usually exceed 1 000 t/h. This is, however, dependent on the level of the stockpile from where the machine is reclaiming.

At a peak digging or reclaim rate of 8 000 t/h, peak surges of up to 2 000 t/h were observed as can be seen from Figure 34. All stacker reclaimers are operated manually and the depth of the bucket wheel is determined by monitoring the reclaimer boom scale reading (yellow line). This makes it difficult to reclaim at a constant rate.

The reason for the high peak surges is due to avalanches on the stockpile caused by reclaiming on the lower benches without first taking away the top material. The blue line in Figure 34 represents a conveyor scale reading after the material has passed through a series of transfer chutes. It is clear that the peaks tend to dissipate over time as the peaks on the blue line are lower and smoother than that on the yellow line.

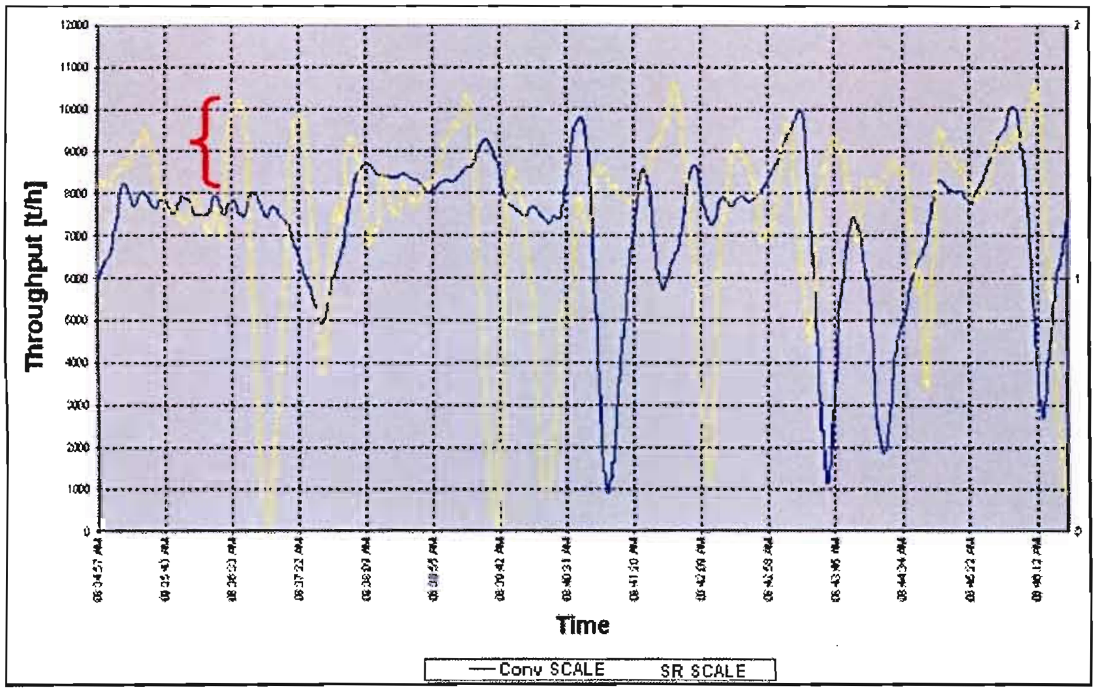


Figure 34: *Peak surges experienced during reclaiming operations*

3.4.7 *Other Problem Areas*

Some blockages on other chutes at the facility occurred while testing the stockyard chutes. These blockages are also shown in Table 3, where the test results are discussed, and to raise awareness that the bottlenecks on site are not only caused by problems on the tested chutes.

A chute downstream from the stockyards encountered a blockage with fine material when the flow rate reached 11 000 t/h. Although this is higher than the test maximum of 10 000 t/h, it still raises concern as to why the chute blocked so severely that it took approximately two hours to clear.

Another bottleneck is the transfer point between the feed conveyor of CV #2 and the discharge chute on CV #2. This transfer point blocked with fine material at a peak just below 10 000 t/h. It should be even worse with coarse ore as previously discussed. Due to the configuration of the head chute, spillage of scraper dribblings is also of great concern. The main stream of material interferes with the flow path of the dribbling material. Therefore, the carry back, scraped off the bottom of the feeding belt, cannot flow down the chute and is pushed over the sides of the chute.

3.5 SUMMARY OF TEST RESULTS

Table 3: *Results from test programme*

Transfer Point	Material Tested	Test No.	Peak Capacity	Blocked Chute
CV #1 / CV #5	Coarse D	9	8 637 t/h	Yes
	Fines N	14	10 000 t/h	No
	Fines N	15	10 000 t/h	No
CV #1 / CV #6	Coarse K	20	9 300 t/h	No
	Fines K	4	10 600 t/h	No
	Fines A	19	9 633 t/h	No
CV #3 / CV #5	Coarse K	5	8 868 t/h	Yes
	Coarse K	6	9 045 t/h	Yes
	Coarse S	12	10 295 t/h	Yes
	Coarse A	17	9 427 t/h	No
CV #3 / CV #6	Coarse K	7	10 195 t/h	Yes
	Coarse K	8	11 000 t/h	Yes
CV #4 / CV #5	Coarse A	16	10 307 t/h	No
CV #4 / CV #6	Fines K	10	10 815 t/h	No (Mech trip on downstream conveyor)
	Coarse K	11	8 000 t/h	No
	Fines A	18	10 328 t/h	No
CV #2 / CV #5	Fines N	13	10 000 t/h	No (Feed to CV #2 blocked)
CV #2 / CV #6	Coarse K	1 & 2	10 153 t/h	No
	Fines K	3	11 000 t/h	No (Blocked chute on downstream transfer)

Table 3 shows the results obtained from all the tests on the stockyard conveyor discharge chutes. Where possible, the same material grade was tested more than once on the same transfer in order to confirm the repetitiveness of the test. The tests shown in red indicate the transfers that blocked at a flow rate of less than 10 000 t/h.

Coarse K and Coarse D are noted as the critical materials for blocked chutes caused by a peak surge. Tests with Coarse K and Coarse S, where a blocked chute occurred at just over 10 000 t/h, can also be considered as failed tests. This is due to the lack of a safety margin 'freeboard' inside the chute. When analysing the video images, a build up can be seen at a flow rate of less than 10 000 t/h.

Table 3 indicates that the fine material did not cause blocked chutes, but it was seen that it did fill up the chute throat area in some cases. Although the coarse material grades are shown as being least suitable for high flow rates, the fine material should not be underestimated for its ability to cause blockages. The finer materials normally have higher clay contents than the coarse grades and therefore stick to the chute walls more easily.

3.6 CONCLUSION

At lower capacities (7 000 t/h to 8 000 t/h) the material appear to flow smoothly inside the chutes without surging or building up in the chute. This flow rate normally does not cause spillage or skew loading on the receiving conveyor belt. On average, as the flow rate approaches 9 000 t/h, the material in the chute throat area starts packing together and finally blocks up the chute.

At transfer rates greater than 9 000 t/h the available area inside the chutes is completely filled up. This causes material to build up or surge inside the chute which eventually results in the chute choking and the inlet flow becomes greater than the outlet flow. Depending on the volume of the chute, the choked state can only be maintained for a certain period of time. If the inlet flow does not decrease it will cause a blocked chute.

Peak surges of up to 10 000 t/h were recorded in most tests which involved a material surge inside the chute but without the occurrence of a blocked chute trip. Although no blocked chute signal was given in these cases, the ability of the chutes to transfer continuously at flow rates of between 9 000 t/h and 10 000 t/h is not very reliable.

Continuous transfer at flow rates approaching 9 000 t/h seems attainable in most cases, but due to the limited 'freeboard' available in the chute throat area, the chutes will easily become prone to blocking. Due to the high peak surges at an increased maximum reclaim rate, the amount of 'freeboard' is critical. If the design criteria of the chute were intended to accommodate these large surges, then all the chutes failed this test. This can be attributed to the fact that no 'freeboard' is left at a maximum reclaim rate of 9 000 t/h.

With the background available from the test programme, it is clear that further investigation is required to obtain a solution to these problems. All the information gathered can be integrated and utilised to provide a solution. A possible solution can then be tested against the problems found with the current transfer chutes.

CHAPTER 4: DYNAMIC CHUTES FOR THE ELIMINATION OF RECURRING PROBLEMS

4.1 PREFACE

After completion of the chute test programme the decision was made to improve the old transfer configuration by installing a dynamic chute. The reason for the dynamic chute is to increase the material speed and decrease the stream cross sectional area. The dead boxes in the older chute slowed the material down and the restriction on transfer height resulted in the material not being able to gain enough speed after impacting on the dead boxes.

A dynamic chute configuration is investigated in this chapter. As the new chute is fitted within the existing steelwork there are certain constraints that determine the new configuration. All the constraints and limitations discussed in this section are specific to the facility under discussion.

The new chute design basically consists of a hood and spoon which retains the kinetic energy in the material stream as it is transferred from one conveyor to the other. This will reduce the creation of dust in the chute and help to discharge the material at a velocity closer to that of the receiving conveyor. The new design does however experience high wear which was not a problem with the old chutes due to large dead boxes.

In order to fit the optimum design of a dynamic chute within the existing structure some changes are required to the positioning of the feed conveyor head pulley. These changes are necessary to accommodate the discharge trajectory from the feeding conveyor.

The radii of the hood and spoon are specified in such a way that the impact wear is reduced significantly. In addition, both the hood and spoon are fitted with a removable dead box section in the impact zones. The incorporation of these sections makes this chute revolutionary in the sense of ease of maintenance.

This new chute addresses all problems identified at the facility and aims to eliminate most of them.

Tests were carried out to identify worst case materials for flow and wear. Different liner materials were tested for both flow and wear conditions. The outcome of these tests is used as the basis for the design of a new chute. As different conditions for flow and wear inside the chute exist, different liners are investigated for each section inside the chute.

4.2 CONSIDERATION OF THE EXISTING TRANSFER POINT CONSTRAINTS

The stockyard consists of four stacker reclaimers and several transfer points feeding onto the two downstream conveyors, resulting in a very intricate system. This system has numerous requirements which need to be addressed when considering a new transfer chute configuration. The transfers under discussion are situated at the head end of the stockyard conveyors.

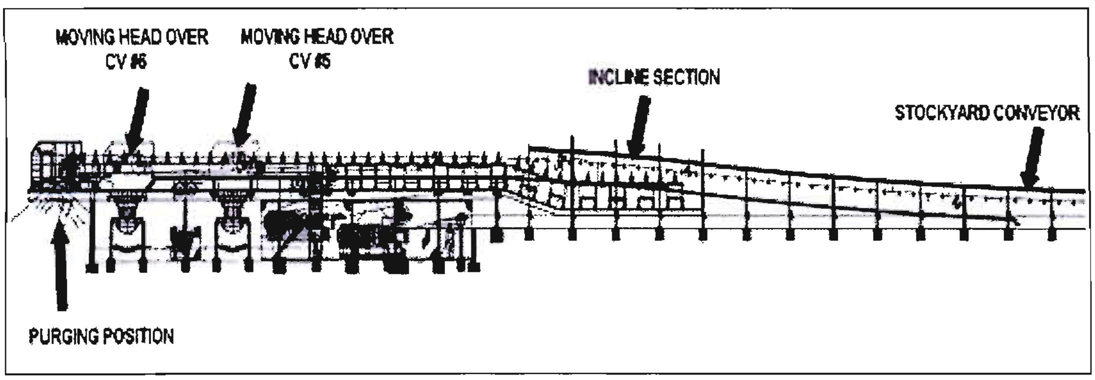


Figure 35: *Stockyard head end layout*

The design of a new transfer chute configuration is restricted to a certain extent by the existing structures on site. Figure 35 provides an overall view of the existing steelwork at the head end of the stockyard conveyor. This existing steel structure can be modified to suit a new configuration but does have some fixed constraints. A good example of these constraints is the transfer height between the stockyard conveyor and the downstream conveyors CV #5 and #6.

On both sides of the stockyard conveyor, stockpiles of ore can be reclaimed and deposited onto the conveyor. This facility allows a certain travel for the stacker reclaimer along the stockyard conveyor for the stacking and reclaiming of material. The most forward position of the stacker reclaimer is at the beginning of the incline section of the stockyard conveyor. As previously explained, any curvature in a conveyor requires a certain minimum radius. When the transfer height is raised, the radius constraints on that curvature in the stockyard conveyor will reduce stockyard space. This means that the storage capacity at the facility will be greatly diminished.

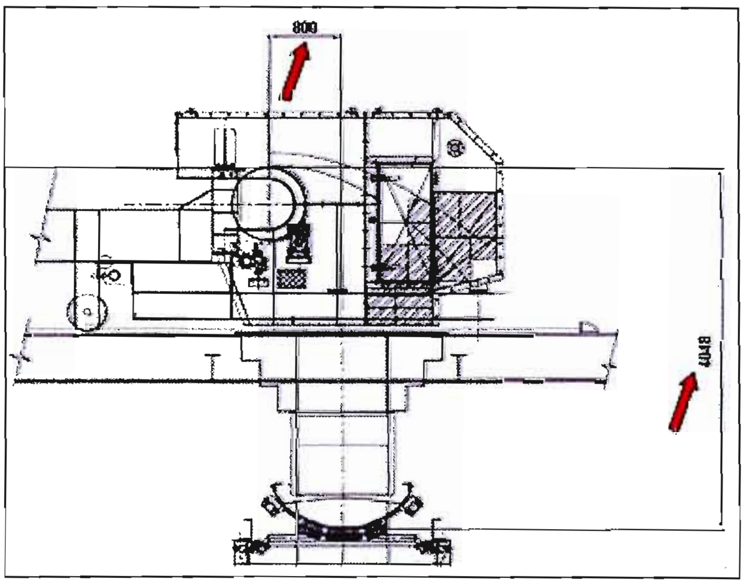


Figure 36: *Dimensional constraints on the existing transfer configuration*

The ideal is to stay within the existing critical dimensions as shown in Figure 36. As functionality of the chute dictates the chute configuration, these dimensions can be modified within certain constraints. These critical dimensions on the existing configuration are:

- Centre of receiving belt to centre of the head pulley - 800 mm
- Bottom of receiving belt to top of the head pulley - 4048 mm

The head pulley can, however, be moved back a certain amount before it becomes necessary to change the entire incline section of the stockyard conveyor. As the moving head moves forward and backward there are idler cars trailing behind the moving head carriage as shown in Figure 35. The purpose of these idler cars is to support the belt when the moving head is feeding onto CV #6 or when it is standing in the purging position.

4.3 DESIGN OF THE CHUTE PROFILE

4.3.1 *Design Methodology*

Proven standard methods for the functional design of the chute are used. These hand calculation methods are based on the Conveyor Equipment Manufacturers Association (CEMA) standard as well as papers from Prof. A.W. Roberts. These are typically calculations for determining the discharge trajectory, optimal radius of the hood and spoon as well as the velocity of material passing through the chute.

In addition to standard methods of carrying out conceptual flow design, it is supplemented by the use of Discrete Element Modelling (DEM) simulation software. This is done to visualise the flow of material through the chute. Results from standard calculation methods are compared to the outputs of the DEM simulations to confirm both results. Chapter 5 will focus on the use of Discrete Element Modelling for the design and verification of chute concepts.

4.3.2 *Design Development*

Figure 37 shows the concept of the hood and spoon chute for a 90° transfer as required by the facility layout. The decision to opt for a hood and spoon chute is based on trying to retain the material velocity when transferring material from the feeding conveyor to the receiving conveyors. Retention of material velocity is critical as the transfer height is restricted. The overall facility constraints for design are as follows:

- Feeding belt speed - 4.5 m/s
- Receiving belt speed - 4.5 m/s
- Transfer height - 4.01 m
- Belt widths - 1650 mm
- Maximum material throughput - 10 000 t/h

As this is a retrofit of an existing facility, some of the facility constraints cannot be changed. This forms part of the design development as it steers the design in a certain direction. Due to the fact that the transfer height cannot be changed, the chute profile will be dependent on the transfer height restriction.

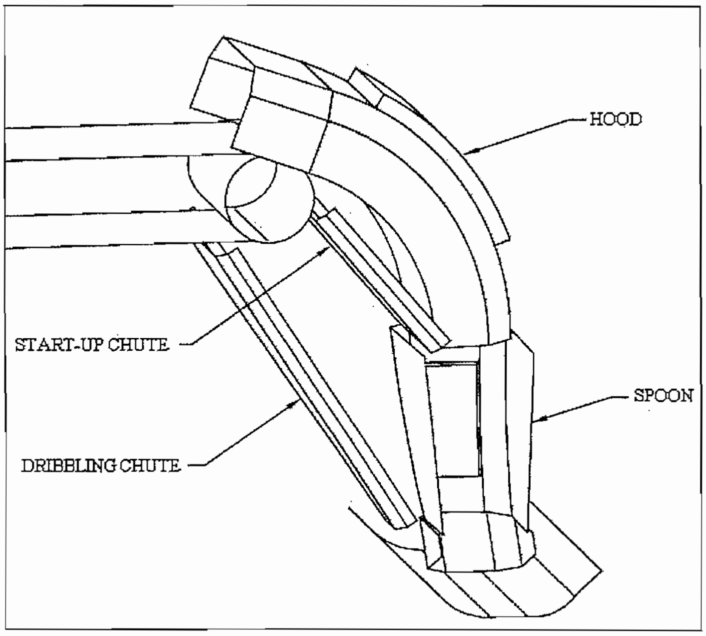


Figure 37: *Hood and spoon configuration for the 90° transfer*

The optimum solution for the correct chute profile, in this situation, would be to move the head pulley back far enough. This should be done so that the hood can receive the material trajectory at a small impact angle and still discharge centrally onto the spoon. However, the head pulley can only be moved back a certain amount. Any further movement will require changes to the structure of the feeding conveyor incline section.

As the stockyard conveyors feed onto two receiving conveyors, the head pulley of the stockyard conveyors is situated on a moving head rail car. This enables the conveyor to discharge either on CV #5 or CV #6 as shown in Figure 25. Taking the movement of the head pulley into account, the moving head rail car can be shortened by 1000 mm in order to move the head pulley back. As stated in the preface, all changes are distinctive to this facility alone. However, it is important to be aware of the consequences of every modification.

4.3.3 *Determination of the Chute Profile*

An important characteristic of the hood and spoon chute design is to ensure a vertical discharge from the hood onto the centre of the spoon. The trajectory is determined using equation (1) in section 2.4. Although various material grades are transferred it does not have a significant effect on the calculated trajectory since the bulk properties of the materials are very similar. It is however important to test the material which will be transferred to obtain the flow angles and wear characteristics. This information guides the liner selection which will be used inside the chute. Liner selection for this case study is discussed in Appendix A.

After the trajectory has been determined, the hood radius can be determined by using equation (2). As the head pulley can move 1 000 mm backward, the best possible hood radius was determined to be 2 577 mm. This hood radius is expected to produce the least possible wear on the impact zone in the chute. The material impact angle at this radius is 11° which is less than the maximum allowable limit of 20°.

The hood radius is chosen to be as close as possible to the radius of curvature of the material trajectory. The point where the hood radius and the trajectory radius cross is known as the impact point. In order to determine the material velocity at any point in the hood, the angle at impact is required. This is the angle on the hood from the horizontal where the material impacts and starts to slide down the hood surface.

In this case the position of impact inside the hood is at 55.87° from the horizontal. In order to determine the material velocity, this angle (θ) is used as the starting point in equation (3). To obtain a complete velocity profile, the angle from where the material impacts the hood is decreased in increments of 5° up to the discharge point which is normally 0°.

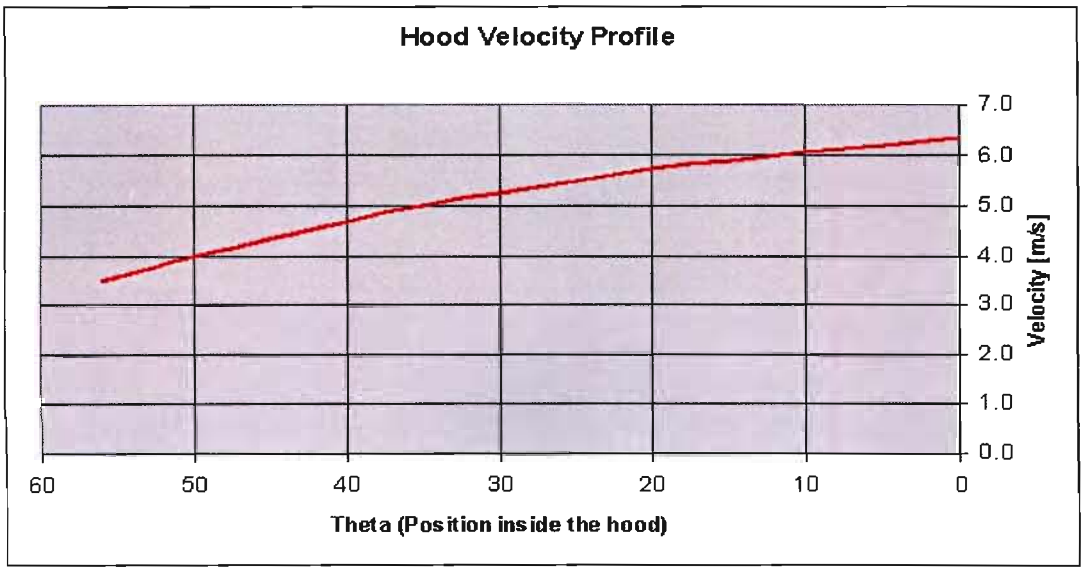


Figure 38: *Hood velocity profile*

The spoon radius is determined in such a way that the wear at the point of impact is kept to a minimum. At the same time the horizontal component of the material exit velocity is as close as possible to the receiving belt speed. Firstly the assumption is made that the initial velocity of material in the spoon is equal to the exit velocity of material from the hood. This yields a spoon entry velocity of 6.33 m/s and can also be seen from Figure 38.

By reiterating various radii for the spoon, the optimum exit velocity, v_e can be obtained. These radii are selected according to the available space in which the spoon must fit and also to produce the smallest impact angle for material discharging from the hood. This table is set up to display the different exit velocities at various spoon radii. The exit velocity is also dependent on the exit angle which is determined by the length of the spoon arc. In this case the spoon radius is chosen as 3 575 mm. An exit angle of 38° from the horizontal yields an exit velocity closer to the receiving belt speed.

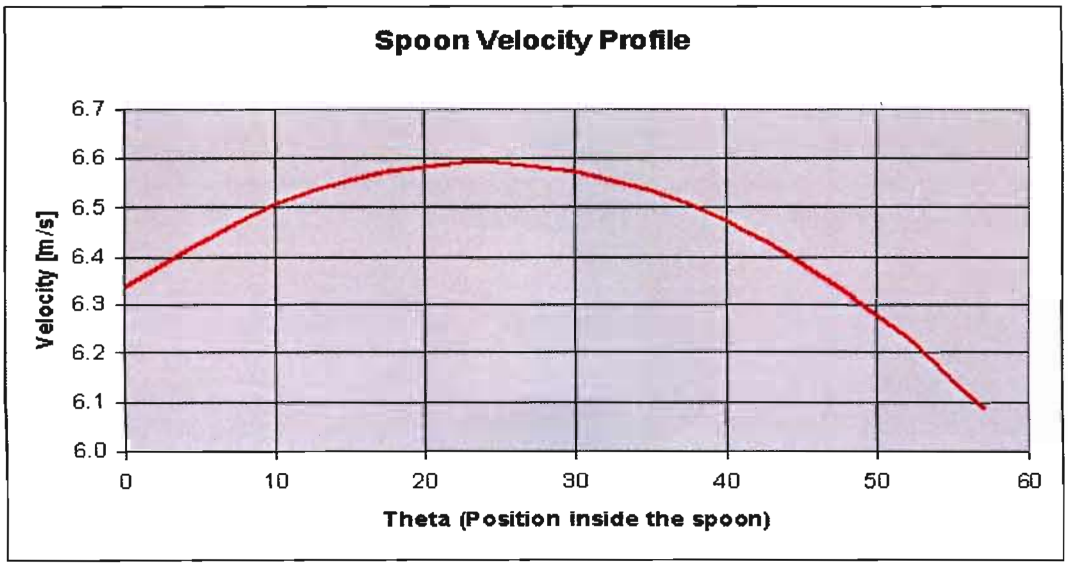


Figure 39: *Spoon velocity profile*

Taken from the origin of the spoon radius, the material position in the spoon at discharge is 57°. The selection of this angle is guided by the geometry of the chute and surrounding structures. This angle is then used to calculate the exit velocity as shown in Figure 39. At this point the discharge angle relative to the conveyor angle is 38°. V_e is then determined to be 6.087 m/s with a velocity component of 4.79 m/s in the direction of the belt. This value is 6.18% higher than the belt speed of 4.5 m/s which is acceptable as it is within the allowable 10% range of variation. Minimal spillage and reduced wear on the receiving conveyor is expected.

Both the hood and spoon have a converged profile. This is done in order to minimise spillage and ensure a smooth transfer of material from the hood to the spoon and from the spoon to the receiving conveyor. The converged profile starts out wide to capture any stray particles and converges to bring the material particles closer together at the discharge. This profile does not influence the transfer rate of the chute as the stream of material through the chute is no more compact than the material on the conveyor belt before and after the transfer chute.

4.4 INCORPORATING A DEAD BOX IN THE IMPACT AREAS

In chapter 1 reference is made to a chute design utilising pipe sections with a rounded profile. The flat back plate is chosen instead of a rounded pipe type section to house the honeycomb dead box configuration. It would be possible to fit the honeycomb into a rounded back section but manufacturing and maintenance would be unnecessarily difficult and expensive.

Furthermore, the cross section profile of the chute shows three sliding surfaces as shown in . These surfaces consist of the back plate, two vertical side plates and two diagonal plates. This is done in order to increase the angle between adjoining plates so that the probability of material hanging up in the corners is reduced. This helps to alleviate the risk of experiencing blocked chutes.

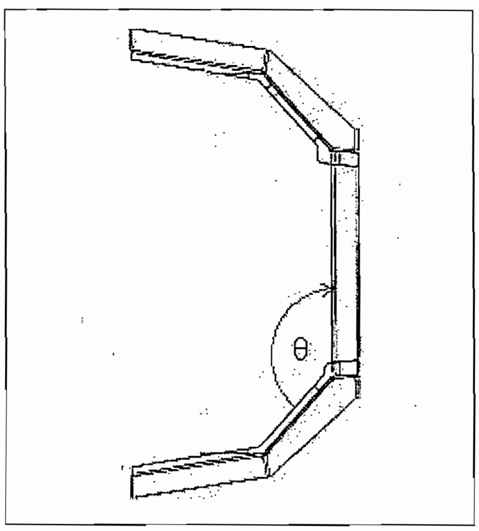


Figure 40: *Chute cross section*

4.4.1 *Honeycomb Wear Box in the Hood*

A honeycomb or wear box is incorporated into this chute configuration in order to further minimise wear in the hood and spoon. The honeycomb configuration is clearly shown in and is typical for both the hood and spoon. Reduced wear will be achieved as impact and sliding will take place on the basis of material on material flow. Ore is captured inside the honeycomb pockets which protects the ceramic lining in the section of the honeycomb and creates another sliding face made of the material being transferred. The ribs in the wear box do not protrude from the sliding face of the chute and, therefore, do not interfere with the main stream flow of material.

Positioning of the honeycomb is critical as the point of impact on the hood needs to be on the honeycomb. This is required in order to assure that the highest material impact is absorbed by a layer of static material inside the honeycomb and not the chute liners. All the basic steps for designing a normal hood and spoon chute are followed. Firstly the angle at impact (θ_c) is calculated to determine where the trajectory of material will cross the radius of the hood. This shows the position of the impact point on the hood. Figure 20 indicates where θ_c is calculated. As previously stated, the angle at impact for this situation is 55.87°. This is calculated using [33]:

$$\theta_c = \tan^{-1}\left(\frac{1}{y^1} \right) \tag{5}$$

And y is defined by equation 1.

This gives an indication as to where the honeycomb should be situated in order to capture the material impacting the hood fully. A flow simulation package can also be used to determine the position of this honeycomb structure. shows an opening for the honeycomb which starts at 40° clockwise from the vertical. This means that there are almost 16° of free space in the honeycomb to ensure that the material will always impact inside the wear box.

There is no set specification as to the size of this free space. This is just to accommodate any surges of material on the feeding conveyor. As discussed in Chapter 3, due to avalanches while reclaiming from the stockpiles, material surges on the conveyors is a reality.

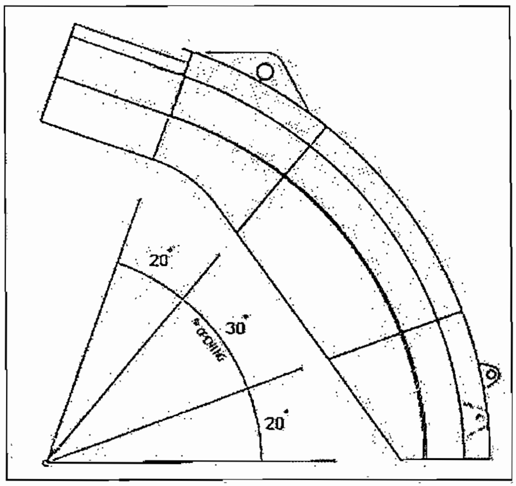


Figure 41: *Honeycomb wear box positioning*

illustrates exactly where this wear box is situated on the back plate of the hood. This configuration is very similar to that of the spoon as both wear boxes only cover the width of the flat back plate of the hood and spoon. The reason for this is that most of the material impact and mainstream flow strikes the back plate.

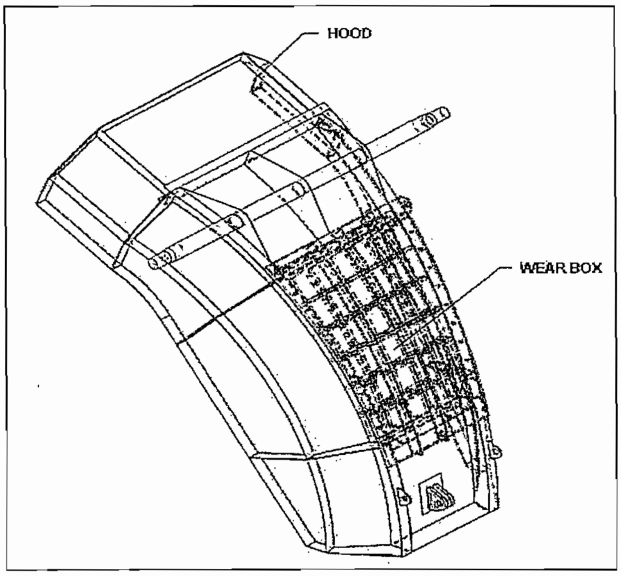


Figure 42: *Wear box in the hood section*

All the horizontal ribs of the honeycomb are spaced 5° apart and there are 5 vertical ribs following the converging contour of the hood as shown in . Spacing of the ribs depends largely on the maximum lump size handled by the transfer. In this case the largest lumps are approximately 34 mm in diameter. The idea is to get as many dead boxes into the honeycomb as possible. These small cavities should, however, be large enough to capture a substantial amount of ore inside.

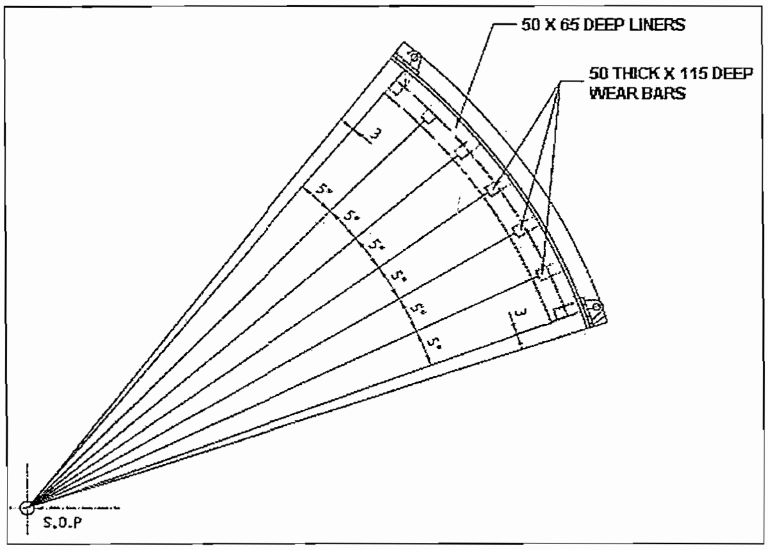


Figure 43: *Spacing arrangement of honeycomb ribs inside the hood*

The two vertical liners on the edges of the honeycomb are only 65 mm high while the rest of the vertical liners are 120 mm high. This is done so that the flat liners in the chute surface can overlap the edge liners of the honeycomb. An open groove between the tiles along the flow of material would cause the liners to be worn through much faster than in normal sliding abrasion conditions. Due to the high wear characteristics of the ore all openings between tiles should be kept out of the mainstream flow.

All the ribs in the honeycomb are 50 mm thick and vary in depth. The vertical ribs protrude the horizontal ribs by 30 mm in order to channel the flow. These vertical ribs are all flush with the surrounding tiles on the flat sliding surface of the hood. All the pockets of the wear box are 120 mm deep measured from the top of the vertical ribs. Again, dimension is dependent on the maximum lump size handled by the transfer. There are no specifications as to the relation between the pocket size and the lump size. These dimensions were chosen to be approximately 4 times the lump size. Computer simulations can be used to test the feasibility of this concept while commissioning of the equipment will ultimately show whether this method works.

4.4.2 *Honeycomb wear box in the spoon*

The honeycomb wear box in the spoon has the same configuration as in the hood. It also covers the entire width of the back plate and fully accommodates the material impacting on the spoon from the hood. The entire spoon is broken up into three sections and the honeycomb wear box is situated in the back section as shown in .

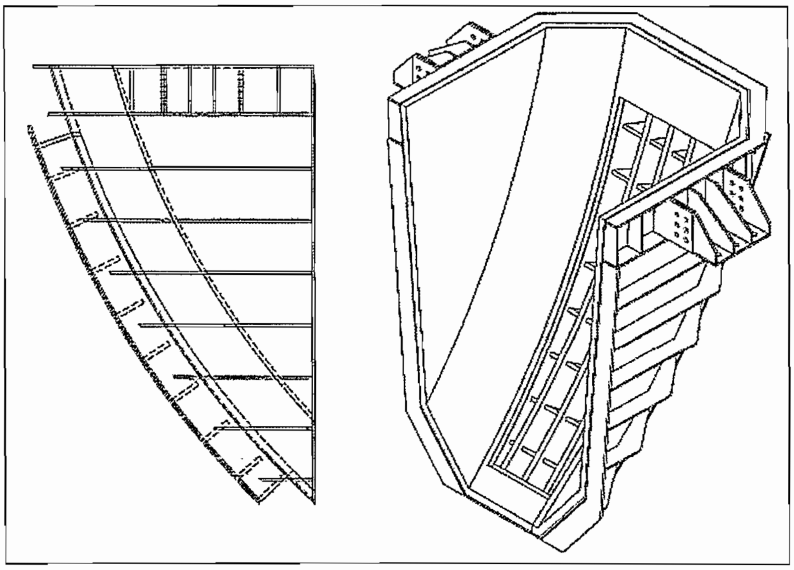


Figure 44: *Wear box in the spoon section*

With almost the same configuration as the hood, the spoon also has a corner liner to ensure a continuous lined face between the flat surface liners and the honeycomb ribs. The detail of these liners and ribs are shown in . A 90° transfer with a hood and spoon chute means that the stream received by the spoon is narrower and longer than the stream received by the hood. This is caused when the material takes the shape of the hood before it is discharged into the spoon. The converged configuration causes the stream to flatten against the sliding surface in the chute.

Due to the spoon honeycomb being a bit narrower than the hood there are only three vertical ribs. The number of ribs had to be reduced to be able to accommodate the preferred cavity size of the honeycomb boxes. These ribs now form two channels in which the stream of material can be directed.

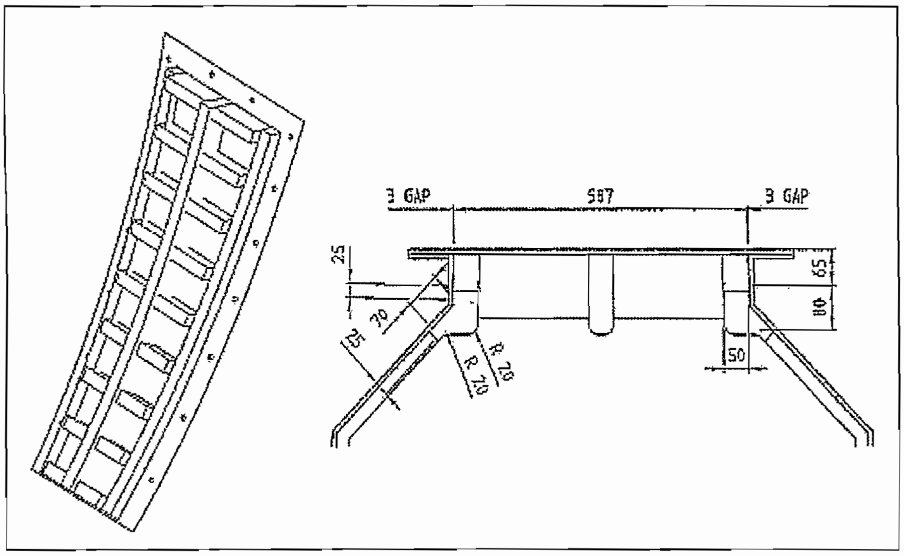


Figure 45: *Liner detail of the spoon honeycomb wear box*

As shown in there is a 3 mm gap between the honeycomb section and the chute plate work. This is to ensure that the honeycomb section can be easily removed for maintenance on the liners. All the edges of the liners have rounded corners to reduce stress concentrations which can cause rapid liner failure.

4.5 DESIGNING THE CHUTE FOR INTEGRATION WITH SYSTEM REQUIREMENTS

The arc length of the spoon back plate is longer and closer to the belt in order to ensure a smooth transfer of material from the chute to the receiving conveyor. A small gap of 75 mm is left between the bottom of the spoon and the receiving conveyor. Due to the fact that material can also be fed from another upstream stockyard conveyor, this configuration will not be suitable. This means that the gap of 75 mm is not enough to allow material to pass underneath the chute.

To accommodate this situation the spoon is split into different sections where the bottom section lifts up to make room for material from behind. In the raised position the gap between the chute and the belt is 450 mm. When the lower belt is loaded to full capacity the material height is 380 mm. This means that the clearance to the belt in the non operational position is sufficient. and show the operational and non operational positions of the spoon.

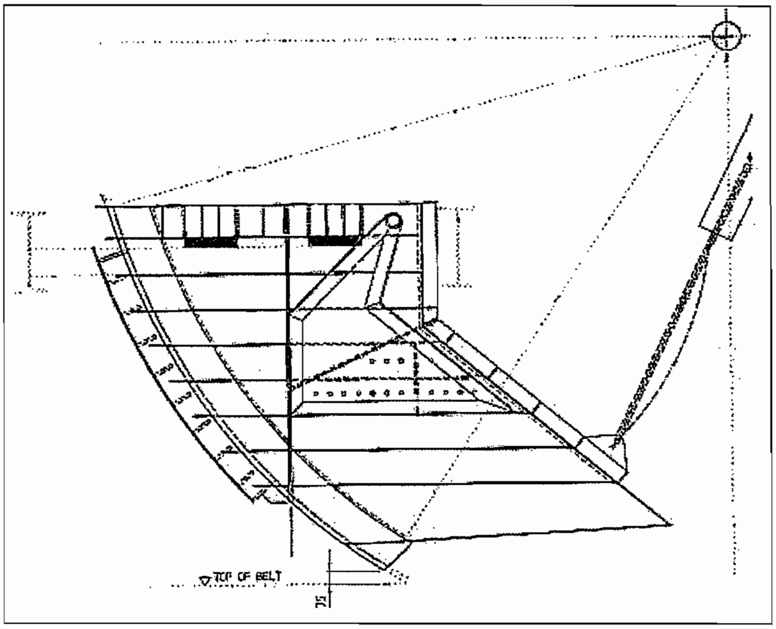


Figure 46: *Spoon in the operational position*

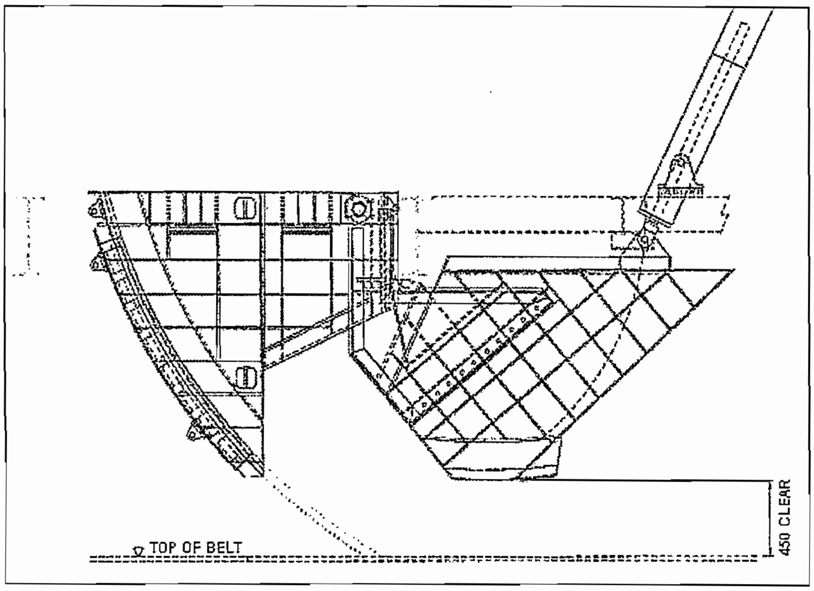


Figure 47: *Spoon in the non operational position*

This section is a discussion on how this new transfer chute configuration should be operated in order to comply with the facility requirements. The bottom section of the chute can be lifted out of the way of material from behind on the receiving conveyor. Therefore, a control philosophy is required for this movement.

Referring to Figure 25, positions A and B indicate where these new chutes will be installed. As previously stated position C is the purging or dump position. and show the actuated spoon section in the operating and non operating positions. The conditions for these positions are explained as follows.

4.6 CONCLUSION

With the consideration of all the facility constraints and a conceptual idea of what the transfer configuration should look like, the design can be optimised. When the feeding belt velocity is known, the material trajectory and optimum chute radius can be determined. This radius and the radius of the spoon must then be corrected to comply with the facility constraints but still deliver the required material transfer rate.

With the high cost implications of regular maintenance intervals on chute liners and facility downtime, a honeycomb structure is incorporated into the high impact areas. The purpose of this honeycomb structure is to form small pockets similar to dead boxes in order to promote material on material flow. This increases the lifetime of the chute liners and reduces maintenance intervals.

This specific transfer chute splits up easily into separate sections and will help to simplify maintenance. The bottom section of the chute is actuated to move up and down depending on whether the chute is in operation or not. This will ensure optimum transfer of material while in operation and provide sufficient clearance when not in operation. This is again guided by the facility requirements.

In the design of all the transfer chute components the physical properties of the ore should always be considered. This determines the chute profile in terms of flow angles and liner selection. With maximum material flow ability, high resistance to sliding abrasion and reduced maintenance cost in mind, 94% alumina ceramics is the liner of choice. This is only in the main flow areas of the chute. For the dribbling chute a polyurethane liner is used to promote the flow of this sticky material.

CHAPTER 5: TESTING AND VERIFICATION OF THE NEW SOLUTION

5.1 PREFACE

Although hand calculations have been a proven method of design for many years, it is important to verify any new chute concept before fabrication and implementation. Confirming the concept can save time and money as it reduces the risk of on-site modifications. Hand calculations only supply a two dimensional solution to the problem which does not always provide accurate material flow profiles.

In recent years a few material flow simulation packages have been developed to aid the design of material handling equipment. The use of software packages can be beneficial to the design process as it gives a three dimensional view of the material behaviour in the chute. This means that changes to the chute concept can be made prior to fabrication.

It is, however, important to verify that the solution obtained from the software package is an accurate reflection of actual design model. Therefore, the material being handled should be thoroughly tested to obtain the correct physical properties required to obtain an accurate simulation result.

The use of material flow simulation software does not replace the necessity for hand calculations. All the basic steps should still be done to derive a conceptual chute configuration. Material flow simulation software should be used as a complimentary tool to analytical hand calculations in the design process.

5.2 SELECTING A TEST METHODOLOGY

Traditionally, transfer chutes were designed by using basic analytical calculations and relying on empirical data from past experiences with other chutes. Mostly these analytical methods only cater for the initial part of the chute such as the parabolic discharge trajectory. It is difficult to determine what happens to the flow of material after it strikes the chute wall [34].

Two methods of verification were usually applied to evaluate a new transfer chute configuration. Trial and error can be used but obviously this is not desired due to the high cost implications. A second method is to build a small scale model of the chute in which tests can be carried out before a final design can be adopted. This physical modelling is, however, time consuming and expensive [34].

Granular or particulate materials are composed of a large number of loosely packed individual particles or grains. The flow of such granular materials forms an intricate part of the materials handling industry. Small reductions in energy consumption or increases in production can have great financial advantages. Therefore, significant efforts are put into improving the efficiency of these facilities. The important role of numerical simulations is becoming more evident in these optimisation procedures [35]. Due to these efforts this technology is becoming more powerful and is easy to use as a verification method for transfer chute designs.

The behaviour of bulk material particles is unique in the sense that it exhibits some of the properties associated with the gaseous, liquid and solid states of matter. The granular state of bulk materials cannot be characterised by any one of these states alone. The research that captures the contact between individual particles in an explicit manner is known as discrete element methods (DEM) [36].

In basic terms, DEM explicitly models the dynamic motion and mechanical interactions of each body or particle as seen in the physical material flow. It is also possible to obtain a detailed description of the velocities, position, and force acting on each particle at a discrete point during the analysis. This is achieved by focusing on the individual grain or body rather than focusing on the global body as is the case with the finite element approach [36].

Figure 48 illustrates two examples of how this DEM software can be applied. Obviously the flow characteristics differ between the applications shown in Figure 48. This is, however, catered for by the mathematical simulation of each particle collision.

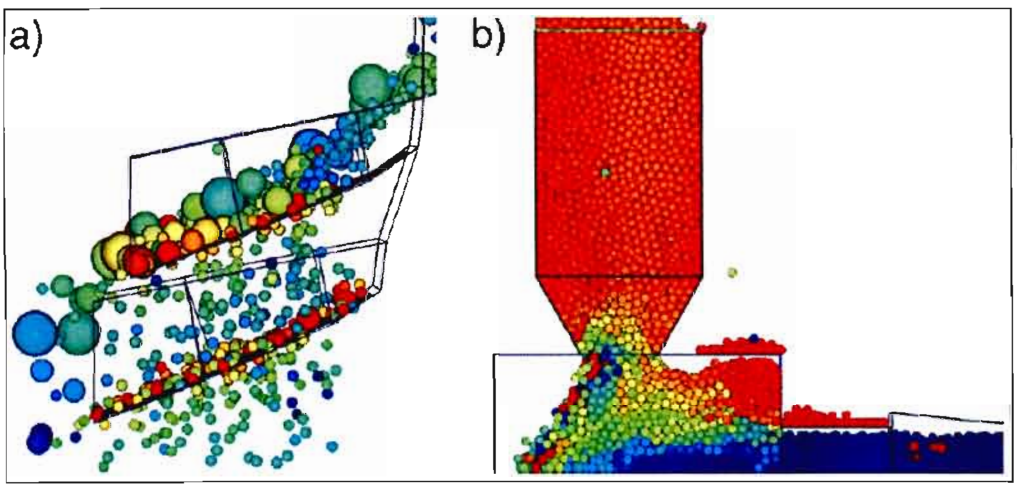


Figure 48: *Flow analysis examples: a) separation and screening, b) hoppers, feeders [36]*

Continuous improvements in the performance of computing systems make DEM a realistic tool for use in a wide range of process design and optimisation applications. During the last 20 years the capabilities of DEM have progressed from small scale two dimensional simulations to much more complex 3D applications. The latest high performance desk top computers make it possible to simulate systems containing large numbers of particles within a reasonable time [37].

According to the institute for conveyor technologies at the Otto-von-Guericke University of Magdeburg in Germany, using DEM for bulk solid handling equipment provides [38]:

- A cost effective method of simulating the utility of materials handling equipment
- Precise control over complicated problem zones e.g. transfer chutes, redirection stations and high wear areas
- The possibility to integrate processes in one simulation such as mixing and segregation
- The possibility to involve the customer more extensively in the design process
- An advantage in the market due to attractive video sequences and pictures of the simulation
- The possibility to prevent facility damages and increase the efficiency of conveyor systems extensively.

As a good example of the advantages of the discrete element method the University of Witwatersrand in Johannesburg did studies on rotary grinding mills. The university studies have shown that the DEM qualitatively predicts the load motion of the mill very well. The improved knowledge of the behaviour of mills can, therefore, increase the profitability of mineral processing operations [39].

This material handling equipment is generally costly to operate and inefficient in the utilisation of energy for breakage. In order to understand the behaviour of mills better, the DEM method is increasingly being applied to the modelling of the load behaviour of grinding mills. These results indicate that this method can be applied successfully in the bulk materials handling industry.

Another example where this technology has been used with great success is with the design of a new load out chute for the Immingham coal import terminal in Britain. By simulating the flow with a DEM package the designers were aided in the fact that they were supplied with a quantitative description of the bulk solid movement through the chute. In the opinion of Professor Franz Kessler (University of Leoben) the Discrete Element Method provides the engineer with unique detailed information to assist in the design of transfer points [3].

These simulation packages are at the moment very expensive and not widely used in transfer chute design. It can be anticipated that the utilisation of these packages will increase as the technology improves and the cost of the software goes down [40]. To get the best value out of the simulation it is important to compare simulation packages and select the one most suitable to the complexity of the design.

Fluent™ is a two dimensional computational fluid dynamics (CFD) software package which can also be used as a chute design aid through the simulation of material flow. It must however be noted that this is not a DEM simulation package. This software package simulates the flow of material by considering the material particles as a liquid substance. The output of the simulation is the same as can be seen in the example of Figure 49. The colours in the simulation represent the average particle spacing [40]. Due to the fact that this package can, at this stage, only deliver two dimensional simulations it is considered inadequate to perform detailed simulations on the intricate design discussed in this dissertation.

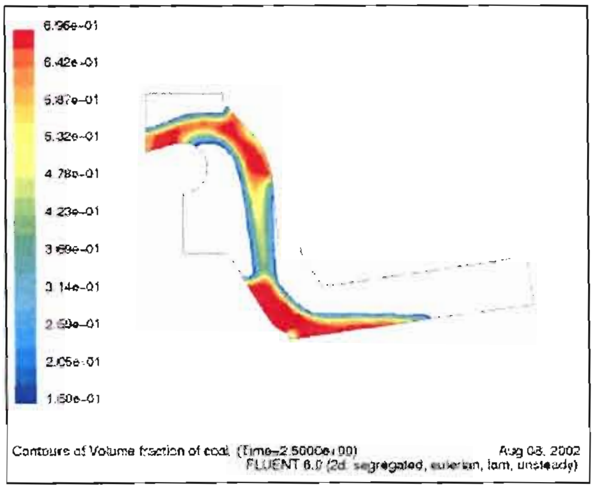


Figure 49: *Simulations results from Fluent™ [40]*

The Overland Conveyor Company provides another alternative to the Fluent software package. Applied DEM is a technology company that provides discrete element software to a variety of users in the bulk materials industry. Bulk Flow Analyst™ is an entry level package that they provide. This package is very powerful in the sense that it can accurately predict flow patterns depending on the accuracy of the inputs. An example of this is shown in Figure 50. It also has the capability to show material segregation, dynamic forces and velocities [41].

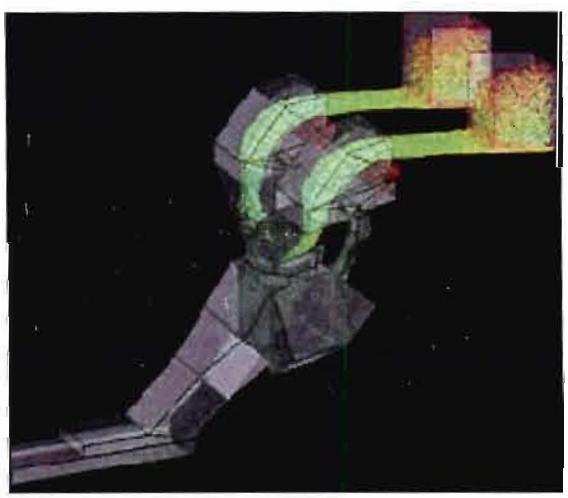


Figure 50: *Simulation results from Bulk Flow Analyst™ [41]*

DEM Solutions is a world leader in discrete element modelling software. They recently announced the release of the latest version of their flow simulation package called EDEM 2.1. This package can be used to simulate and optimise bulk material handling and processing operations [41]. Due to the capabilities of this software package it is a very attractive option for designing transfer chutes.

With the development of EDEM 2.1, DEM Solutions worked in collaboration with customers in the Bulk Handling, Mining and Construction, Pharmaceutical, Chemical and Agricultural sectors. This enables the end users to perform more sophisticated particle simulations specific to their unique applications. Also incorporated into this package is the ability and flexibility to customise and personalise advanced particle properties [42].

This specific package has been proven successful by industry leaders. Martin Engineering (Neponset, Illinois) is a leading global supplier of solids handling systems. This company continues to expand their use of EDEM software in design optimisation and development of bulk materials handling products. These optimisation and development actions include all aspects of conveyor systems and transfer points for numerous industrial sectors [43].

There are several other DEM simulation packages such as ESYS Particle, Passage-DEM and YADE. However, none of these software packages seem be major industry role players in the discipline of chute design, although they might have the capability. In adjudicating the three big role players in bulk material flow simulation packages there are a few factors taken into consideration. It appears that the advantages of 3D capabilities are non negotiable. Therefore Fluent™ is not really a consideration. From the literature review of the Bulk Flow Analyst™ and the EDEM packages it seems that these two will provide more or less the same performance. It does seem, however, that the EDEM software is a bigger role player in various industries. Due to the possible future capabilities of EDEM through its association with numerous industries, this simulation package is the software of choice.

In order to retrofit or design a new transfer point with the aid of the selected DEM software package there are a few steps that a designer must follow to gain the full benefit of this tool [36]:

1. An accurate 3D or CAD representation of the new or old transfer chute must be rendered
2. Identify restrictions and limitations in terms of chute geometry and manufacturing
3. Identify desired design goals (i.e. dust emissions, flow restrictions, etc.)
4. Identify representative material properties and particle descriptions
5. In case of a retrofit, make design changes to chute geometry with CAD
6. Simulate the performance of the new design using DEM software
7. Evaluate results obtained from the simulation (reiterate steps 5, 6 and 7)
8. Perform and finalise detail design steps
9. Manufacture
10. Installation

The above mentioned steps found in references [6] and [36] only provides information regarding retrofitting or designing chutes with the aid of DEM. Although it is a powerful design tool, the design process should not discard the use of analytical hand calculations. Some of the most important design decisions regarding chute profiles are made with analytical hand calculations such as plotting the material trajectory.

5.3 DETERMINATION OF MATERIAL PROPERTIES

The discrete element method is a promising approach to the simulation of granular material interaction. The accuracy of the outcome of the simulation is, however, dependent upon accurate information on the material properties and input parameters [44]. These inputs basically consist of the following fundamental parameters: size and shape factors, bulk density, angle of repose, cohesion and adhesion parameters and restitution coefficients [45].

The determination of most of these parameters are explained and defined in the following paragraphs. The parameters that are changed in the simulation according to the reaction of the flow are not discussed and are typically parameters such as the internal coefficient of friction between a number of particles. A collaborated effort by the bulk handling industry aims to find ways in which all parameters can be accurately determined through scientific methods. This has however still not been achieved. The objective is to achieve a realistic representation and therefore some parameters are altered in the simulation.

It is important to note that the computation time increases as the particle size becomes smaller and the amount of particles increase. In most granular flow problems the characteristics of the material stream are largely determined by particles greater than 10 – 20 mm in size [45]. Therefore, in order to reduce computation time, the selected particle size for simulations should be the same as the largest particles handled by the facility namely 34 mm diameter.

Although fines have a higher internal friction coefficient and more cohesiveness, these properties can be averaged into the input parameters to obtain the same overall effect [45]. Therefore, only a single particle size is used in the simulation and the properties optimised to obtain the same result under actual operating conditions. Some of the material properties can be easily obtained from the facility. The rest of the properties are obtained from tests carried out by expert consultants in this field.

The size factor and bulk density are obtained from the facility. Material tests carried out by external consultants provide the coefficient of friction and also the wall friction angle. This is the angle at which the material will start to slide under its own mass. To determine these material properties the external consultants normally use sophisticated and expensive equipment. Data gathered from these tests are used for the hand calculation of the chute profile. The angle of repose can normally be observed from a stockpile and is the angle that the side of the stockpile makes with the horizontal.

For the DEM simulation the coefficient of friction is one of the main determining factors of the wall friction angle. Data provided by the material tests can not be used as a direct input into DEM. In the software package the coefficient of friction is represented by a factor between 0 and 1. The material test data can however provide some insight into where on this scale the factor is. This factor can be derived from a few small simulation iterations as there is no method of direct conversion between the test result data and the DEM input.

To determine this factor a plate is modelled with a single layer of particles. This plate is then rotated within the simulation at approximately 2° per second. As soon as the particles begin to slide the time is taken from which the angle can be calculated. This process is repeated with different friction coefficients until the correct wall friction angle is obtained. After the coefficient of friction factor is determined between the particles and the chute wall, the material restitution factor and coefficient of internal friction can be obtained.

The restitution factor is obtained by measuring the rebound height of a particle when it is dropped from a certain height. This is usually difficult to determine due to the variation in shape of the material particles. If the particle lands on a surface it rarely bounces straight back up. Therefore, the test is repeated numerous times and an average is taken to obtain the final result.

Coefficient of internal friction is a property that describes the particles ability to slide across each other. A simulation is set up to create a small stockpile of material particles. The angle of repose can be obtained by measuring the average apex angle of the stockpiles. In this simulation the coefficient of internal friction and restitution factors are iterated. This is done in order to simulate the accurate behaviour of particles falling onto the stockpile and forming the correct angle of repose. Figure 51 shows what this simulation typically looks like.

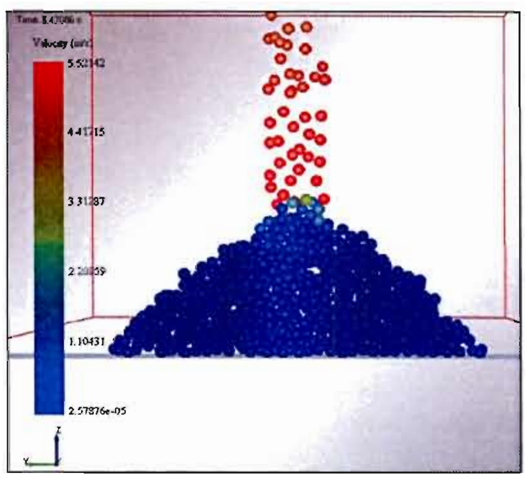


Figure 51: *Determination of material properties for an accurate angle of repose*

5.4 VERIFICATION OF THE SELECTED TEST METHODOLOGY FOR THIS APPLICATION

The best verification is to compare the simulation results with an actual material flow situation. Therefore, a comparison is made between the actual flow in the existing transfer configuration and the simulation of this same transfer. This is also a good test to see if the parameters changed in the simulation were done correctly.

During the chute test programme CCTV cameras were installed in the problem transfer chutes at the facility. The cameras are positioned to provide an accurate view of the material flow behaviour inside the chutes. As explained in Chapter 3, the behaviour of the material flow inside the chutes changes with the variation of ore type.

Due to the fact that only 34 mm diameter particles are used in the simulation, a test using coarse ore was chosen for the verification of the simulation. Therefore, test #12 is used as reference for the verification. In this test, coarse S with the particle size distribution between 28 mm and 34 mm was used at the transfer from CV #3 to CV #5.

Figure 52 shows an image taken from the CCTV camera inside the transfer chute between CV #3 and CV #5. The red line indicates the top of the chute throat opening and the yellow arrows show the top of material flow. This screen shot was taken at a flow rate of 10 000 t/h. It can be deduced from this view and the chute test work that the chute is choking at a throughput rate of 10 000 t/h.

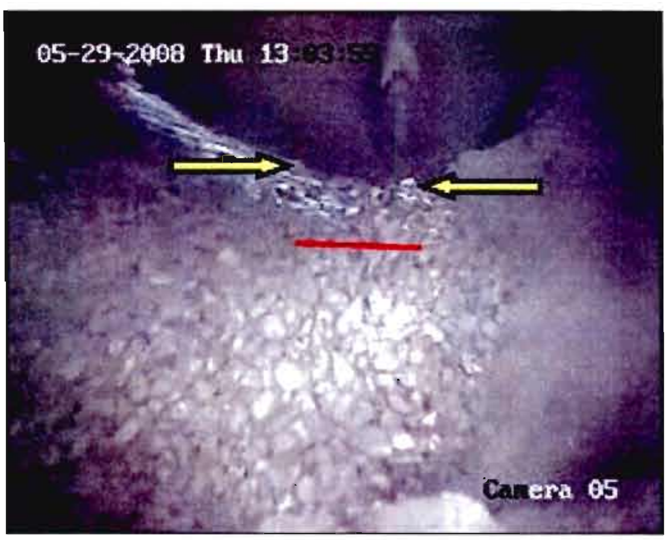


Figure 52: *Actual material flow with coarse S at 10 000 t/h*

The transfer chute from Figure 52 was modelled in CAD and the model imported into the discrete element package, EDEM. All the material input parameters as discussed in section 5.3 were used in the simulation. 10 000 t/h was used as the flow rate parameter in an attempt to simulate and recreate the situation as shown by Figure 52.

Test #12, of the chute performance tests, gave the following results which can be compared to the EDEM simulation:

- Chute started to choke rapidly at 10 000 t/h
- Slight off centre loading onto the receiving conveyor CV #5
- A lower velocity layer of material close to the discharge of the chute
- Material roll back on the receiving conveyor due to significant differences in the velocity of the material flow and the receiving conveyor.

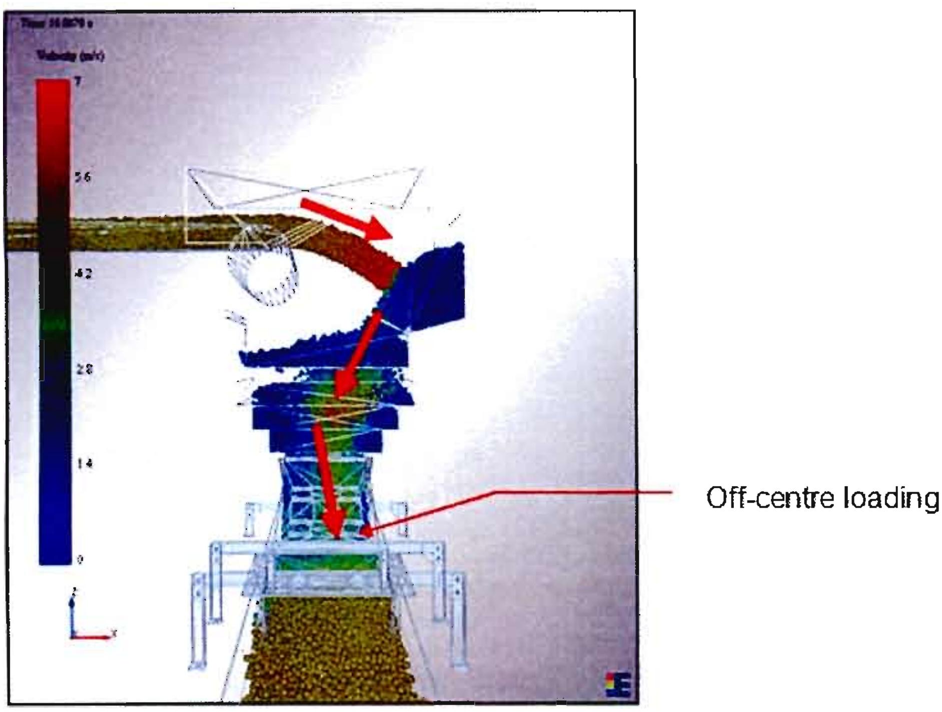


Figure 53: *Material flow pattern through the existing chute*

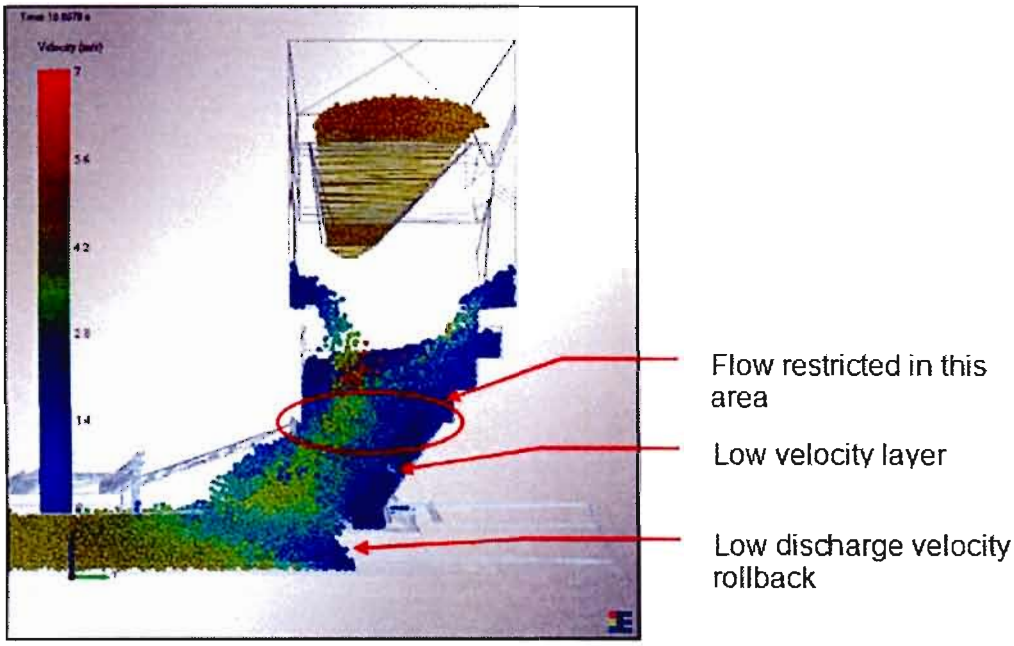


Figure 54: *Cross sectional side view of material flow through the existing chute*

Figure 53 shows the material flow pattern in the existing chute where the thick red arrows indicate the direction of flow. The legend on the left of the figure indicates the material velocity in m/s. Slow flowing material is shown in blue and the colour turns to red as the material velocity increases. Slight off centre loading onto the receiving conveyor CV #5 can be seen from Figure 53. This correlates well with the actual observations during the physical testing of this transfer point.

Figure 54 shows the more determining factors for correlation between actual flow and simulated flow where the legend on the left indicates the material velocity in m/s. This is a cross sectional view through the centre of the chute. From this view a build up of material can be seen in the chute throat area. The slow flowing material on the back of the chute also helps to restrict the flow. Due to the fact that the material speed at the discharge of the chute is much slower than the receiving belt speed, a stack of turbulent flowing material is formed behind the discharge point on the receiving conveyor.

There is a good correlation between the simulated and actual material flow pattern. The simulation method can therefore be considered as a valid alternate or additional method to standard analytical chute design. Attention should be given though to the input of material properties in order to obtain a realistic result.

5.5 VERIFICATION OF NEW CHUTE CONFIGURATION AND OPTIMISATION OF THE HOOD LOCATION

After establishing that the DEM is a reliable design and verification tool, the new transfer chute configuration can be simulated. Firstly, this configuration is modelled without the honeycombs inside the hood and spoon. This is done in order to verify the material flow pattern and velocity through the hood and spoon. Results obtained from this simulation can then be compared to the hand calculation results. An iterative process is followed with simulations and hand calculations to obtain the best flow results. The simulation results are shown in Figure 55 and Figure 56.

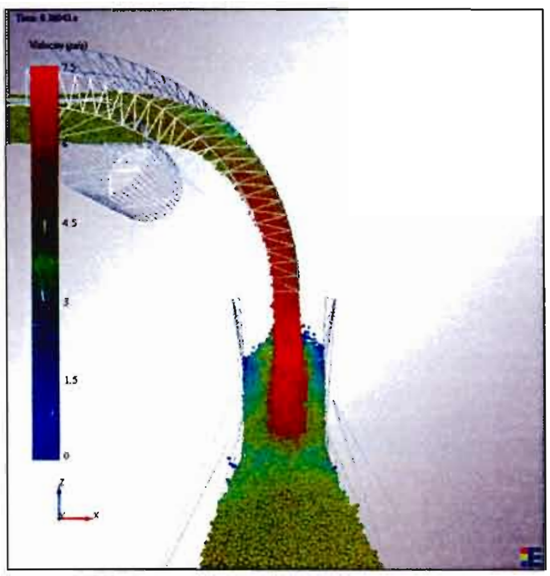


Figure 55: *Material flow through hood at 10 000 t/h*

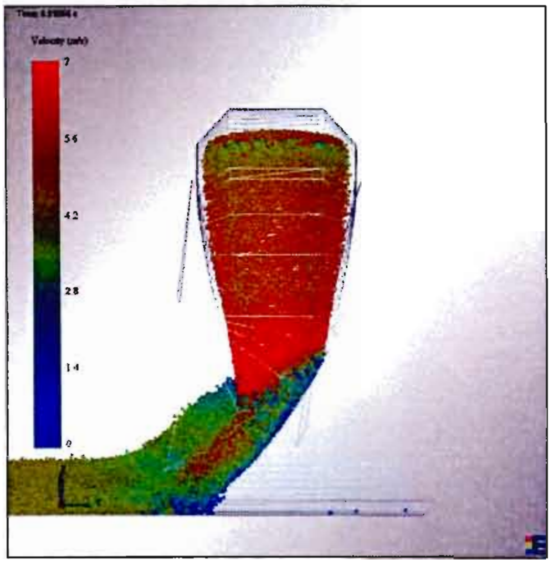


Figure 56: *Material flow through spoon at 10 000 t/h*

The hood velocity profile shown in Figure 38 gives the same result as obtained from the DEM simulation. The calculated hood exit velocity is 6.33 m/s. This is the same result obtained from the simulation and shown by the red colouring in Figure 55. As the material enters the spoon it is falling under gravity and, therefore, still accelerating. At impact with the chute wall it slows down and exits the spoon with approximately the same velocity as the receiving conveyor.

Figure 56 shows the material flow through the spoon section. This can also be compared to the spoon velocity profile in Figure 39. The behaviour of the material inside the spoon, as shown by the simulation, correlates with the results obtained from the hand calculations. This is another indication that with accurate input parameters the DEM can be used as a useful verification tool.

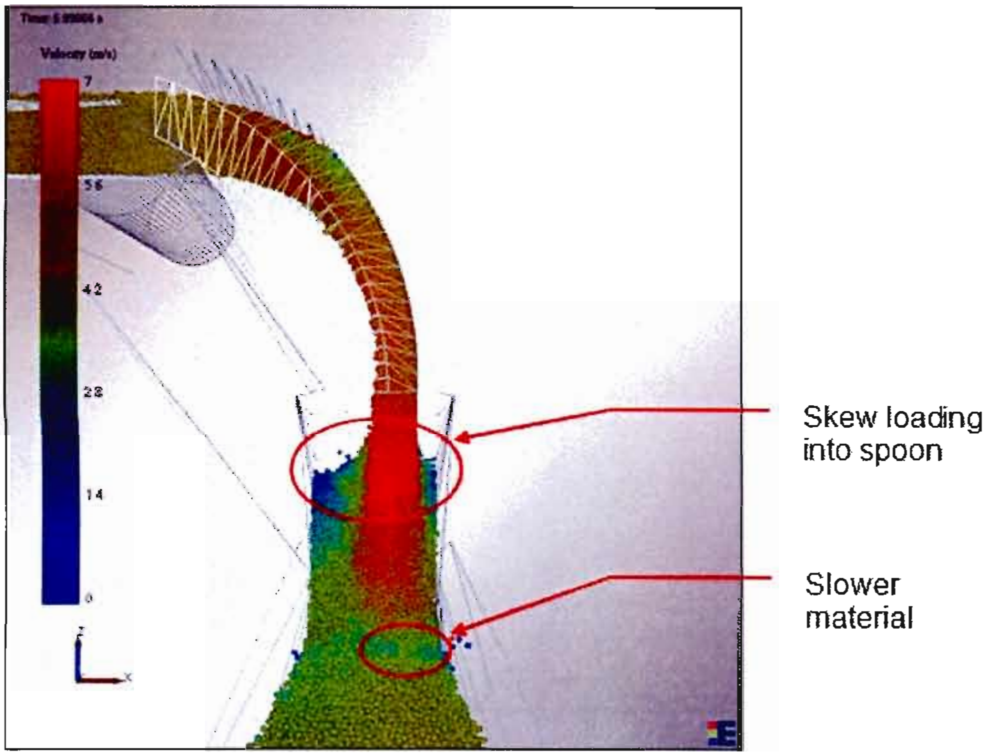


Figure 57: *Determination of the optimum hood location*

The hood is supported by a shaft at the top and can be moved horizontally. This function is incorporated into the design in order to optimise the hood location during commissioning of the transfer chute. It is critical to discharge centrally into the spoon in order to eliminate skew loading onto the receiving conveyor.

Figure 57 illustrates the effect that the hood location has on material flow. When comparing the flow from Figure 55 to the flow in Figure 57, it is clear that skew loading is a direct result of an incorrect hood position. The circled area in Figure 57 illustrates how the flow reacts to the incorrect hood location.

Material is discharged to the right side of the spoon which causes a slight build-up of material on the left. This causes the material to flow slightly from side to side as it passes through the spoon. Figure 57 indicates that the material to the right at the spoon discharge is slightly slower than the material on the left. This is a clear indication of skew loading onto the receiving conveyor.

The material flow pattern in Figure 55 is symmetrical and, therefore, will not cause skew loading. The DEM can give a good indication of the required hood setup before commissioning. However, adjustments can still be made during the commissioning process. The tracking of the receiving belt should give a good indication of when the hood is in the optimum position.

5.6 EFFECT OF THE HONEYCOMB STRUCTURE IN HIGH IMPACT ZONES

The purpose of the honeycomb dead box structure in the high impact zones is to capture material inside the pockets and induce material on material flow. This requires that the material inside the honeycombs should be stationary while the main stream material flow moves over the dead boxes. DEM can, therefore, be set up in such a way that the material velocities can be visualised inside the chute.

In Chapter 4 the logic of how this honeycomb should be structured and positioned was discussed. The simulations shown in Figure 58 and Figure 59 illustrate how a DEM package can also be used to determine the positioning of these honeycomb structures. Impact points in the hood and spoon must be inside the honeycomb in all situations of flow inside the chute. The spacing of dead box pockets can be altered to ensure that a continuous layer of stationary material is formed in the honeycomb area. Various geometries for this honeycomb structure can be simulated with DEM to obtain the best results.

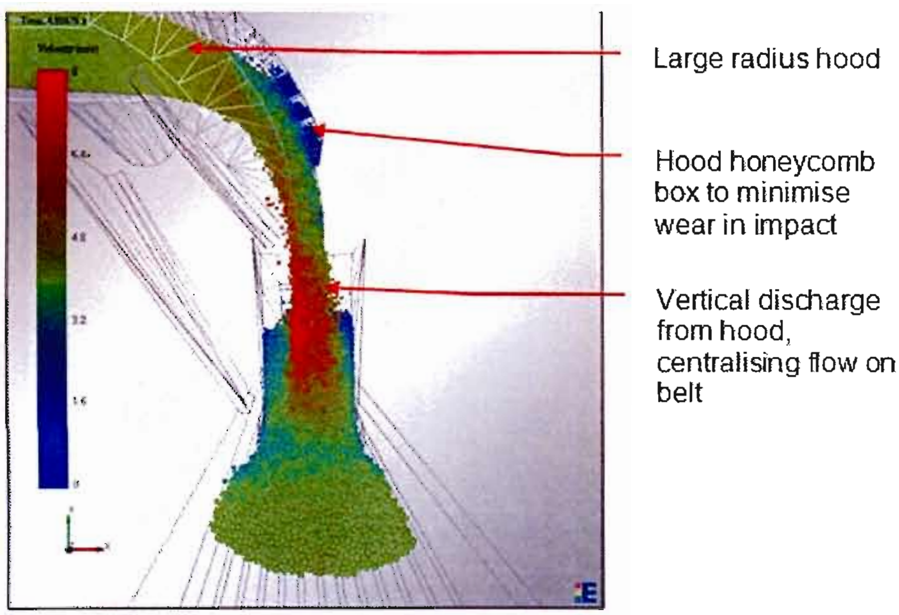


Figure 58: *Material behaviour through hood*

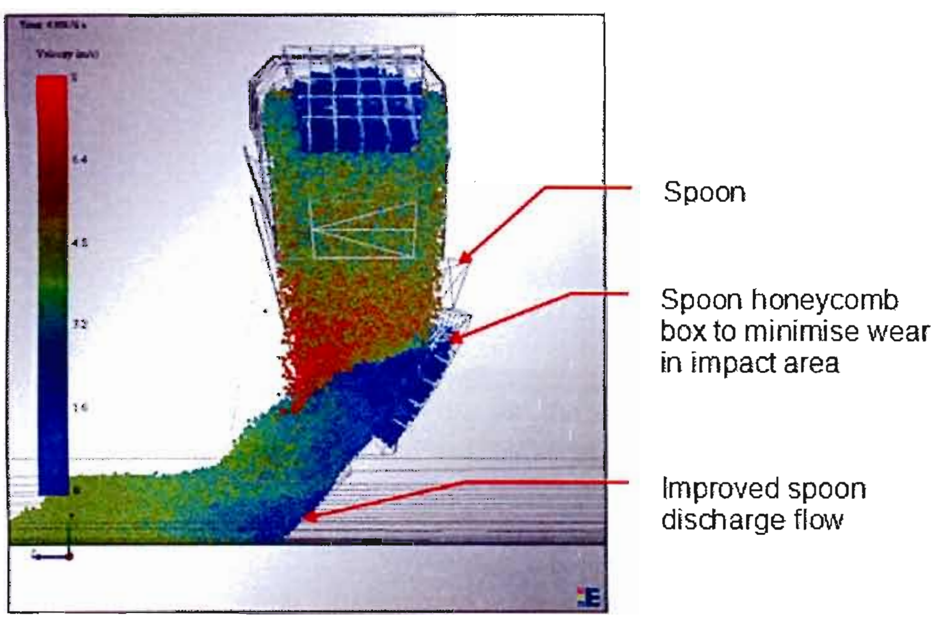


Figure 59: *Material behaviour through spoon*

The legends on the left of Figure 58 and Figure 59 indicate the material velocity in m/s. Dark blue indicates stationary material and bright red indicates a maximum material velocity of 8 m/s. Using this information, the functionality of the honeycomb dead boxes can now be analysed. The velocity of the material captured by the dead boxes is indicated as dark blue. This means that all the material in the dead boxes is stationary.

With the result obtained from the DEM simulation it is clear that material on material flow will be induced by the honeycomb dead boxes. The pockets of the honeycomb capture the material and will, therefore, have reduced wear in the high impact areas. This material on material flow does, however, induce a coarser sliding surface than the smooth ceramic liner tiles. Due to the high velocity of material through the chute the effect of the coarser sliding surface is, however, minimised.

5.8 CONCLUSION

The Discrete Element Method is proven to be a successful design and verification tool in the bulk materials industry. This method is used widely in the global bulk materials industry. The successful outcome of the DEM simulation is, however, dependent on the correct material input parameters. Some of these parameters are readily available from the facility that handles the material. The rest of the parameters can be determined by setting up simple test simulations with DEM.

To verify that the DEM simulation is a correct indication of the actual condition, the simulation is compared to CCTV images taken from the same transfer chute. The results show that the DEM simulation does provide a true reflection of the actual material flow through the transfer chute. Therefore, the same material input parameters can be used to simulate the new transfer chute configuration.

From the simulations done on the new transfer chute configuration the effect of the honeycomb dead boxes can be examined. These simulation results show that the honeycomb dead box configuration is effective in capturing material inside the honeycomb cavities. This results in material on material flow and reduces impact abrasion on the ceramic chute liners.

Results obtained from the DEM simulation of the new transfer configuration are compared to the hand calculation results. This comparison indicates that the material velocity calculated in the hood and spoon correlates well with the material velocity calculated by the DEM. The overall results obtained from simulating the new transfer chute configuration have been shown to provide a true reflection of the actual flow through the chute.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS AND RECOMMENDATIONS

Bulk materials handling is a key role player in the global industrial industry. Within this field the industry faces many challenges on a daily basis. These challenges, as with any industry, are to limit expenses and increase profit. Some of the limiting factors of achieving this goal in the bulk materials handling industry are: lost time due to unscheduled maintenance, product losses due to spillage and high costs incurred by increased maintenance.

The focus of this study was on the optimisation of transfer chutes and investigations were carried out to determine the core problems. These investigations were done by observing and monitoring various grades of iron ore passing through transfer chutes known to have throughput problems. The core problems were identified as high wear on liners in the impact zones, skew loading on receiving conveyors, material spillage and chute blockages.

These problems cause financial losses to the facility either directly or indirectly. Direct financial losses can be attributed to the frequent replacement of chute liners while the indirect financial losses are caused by facility down time. This is why it is imperative to optimise the manner in which the transfer of material is approached. A new transfer chute configuration addresses the problems identified at the facility and the core concepts can be adopted at any bulk materials handling facility.

This new concept examines the utilisation of the hood and spoon concept rather than the conventional dead box configuration. By using the hood and spoon configuration the material discharge velocity is utilised and carried through to the discharge onto the receiving conveyor. Adding to this design is a honeycomb dead box configuration in the high impact zones of the hood and spoon. This initiates material on material flow and prolongs the lifetime of the chute liners.

The radius of the hood should be designed so that it follows the path of the material trajectory as closely as possible. Some facility constraints prohibit this hood radius from following exactly the same path as the material. The radius of the spoon is designed in such a manner that it receives the material from the hood and slows it down while turning it into the direction in which the belt is running. Ideally, the material should be discharged from the spoon at approximately the same velocity as the receiving conveyor.

If this can be achieved then some major problems suffered by the industry will have been resolved. With the hood having almost the same radius as the material trajectory impact wear on liners can be significantly reduced. By discharging material from the chute onto the receiving conveyor at the same velocity as the conveyor belt, excessive belt wear and material spillage will be avoided. Further optimisation is however still possible by investigating the implementation of various skirting options to the side of the conveyor.

This new transfer chute configuration also boasts an articulated bottom section in the spoon. The purpose of the adjustable bottom section is to create greater clearance below the spoon. This will allow material on the belt below, to pass unimpeded underneath the spoon. In some cases there can be several chutes in series that discharge onto the same conveyor. In these cases it is beneficial to incorporate an articulated chute in order to have the capability of having a small drop height between the discharge point in the chute and the receiving conveyor. This low drop height also minimises turbulent flow at the chute discharge point on the receiving conveyor.

The most unique feature to the new design is the implementation of the honeycomb dead box configuration in the high impact zones. Due to these high impact areas the liners will experience the most wear. This section of the chute is flanged and can be removed separately from the rest of the chute to aid maintenance. In most maintenance operations it may only be necessary to reline this small section of the chute. Costs are minimised by reducing the time required for maintenance and the cost of replacing liners.

Previously, testing of new transfer chute configurations normally involved implementing the chute and observing its ability to perform according to specification. This can, however, be a costly exercise as it is possible that further modifications to the chute will be required after implementation. Therefore, it is beneficial to verify the new chute configuration before implementation.

This is done by simulating the material flow through the chute using Discrete Element Method. A comparison was done between the actual flow in an existing chute and the simulated flow in the same chute configuration. This comparison showed the same result obtained from the simulation and the actual material flow. This method can therefore be used as an accurate simulation tool for evaluating transfer chute performance.

The mathematical calculations describing the material flow in and over the honeycomb dead box structures are complex. Therefore simulation models are used to show the material behaviour in those areas. Simulations show that the material captured within the dead boxes remains stationary, thus protecting the ceramic liners behind it. This is the desired result as it prolongs the life of the chute liners and reduces maintenance frequencies.

If the work is done efficiently it normally takes two days to remove a worn chute of this configuration fully and replace it with a new one. This is normally done once a year due to the design lifetime of the chute. With the new chute configuration this maintenance schedule can be reduced to two hours, once a year, for the replacement of the honeycomb sections only. The exposed face of the honeycomb ribs will wear through until the efficiency of the honeycomb design is reduced.

This specific iron ore facility has approximately fifty transfer points. During this exercise only two of these transfer points were replaced with the new chute configuration. The combined annual maintenance time for replacement of these 50 chutes is 100 days. If the new chute philosophy is adopted on all these transfers the annual maintenance time can be reduced to as little as 100 hours. This excludes the unplanned work for cleaning of spillages and fixing or replacing worn conveyors.

There are significant benefits to investigating the problems at specific transfer points before attempting a new design. This gives good insight into where the focus should be during the design process. Early identification and understanding of the problem areas is essential for a new chute configuration. The new design features can provide a vast improvement and a large benefit to the bulk materials handling industry.

6.2 RECOMMENDATIONS FOR FURTHER STUDY

During the chute performance tests it was noted that avalanches on the stockpiles during reclaiming of material causes peaks on the conveyor systems. These peaks in the material stream increase the probability of blockages in the transfer chutes. As a result, material spillage occurs and the conveyor belts can be easily overloaded.

This occurrence creates the requirement for further studies on the reclaiming operations. All stacker reclaimers are operated manually which creates ample room for error. Investigations can be done to determine the value of automating the reclaiming operations. Manual interaction cannot be avoided, but an automated system will reduce the possibility for error.

Visual inspections on the transfer chute liners indicate that the material tends to erode the liners away quicker in the grooves between liner plates or ceramic tiles. This occurrence seems to be worse in areas of the chute where the material velocity is the highest.

This problem was specifically noticed with ceramic liner tiles. The tiles are glued to the chute surface with an epoxy and this substance also fills the crevices between the tiles. This epoxy is, however, not resistant to any type of sliding or impact abrasion. If the material gains speed in such a groove between the tiles it simply erodes the epoxy away. Studies to reduce or even eliminate this problem should be examined.

In some situations the layout and configuration of the chute prohibits the tiles from being inserted in a staggered manner. Studies can be done on the composition of this epoxy in order to increase its resistance to sliding and impact abrasion. By doing so the lifetime of the chute liners can be increased which will result in minimised facility down time due to maintenance.

It seems that it is a global industry problem to find accurate scientific methods of determining material input parameters for DEM simulations. Although most of the material properties can be determined through testing, it is still a challenge to convert that information into a representative input parameter into DEM. It is therefore recommended that further studies be undertaken to determine a method by which material test data can be successfully converted into DEM input parameters.

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APPENDIX A: MATERIAL TESTS AND LINER SELECTION

MATERIAL TEST WORK AND LINER SELECTION

Material samples were taken from the stockpile area for evaluation and testing. These samples represent the worst case materials for impact wear and flow problems. Tests were conducted by external consultants as this is a speciality field. Therefore no detail information on how the tests are conducted is currently available. Results from these tests should indicate the worst case parameters for chute design according to each specific liner type tested.

The material handled by the facility varied from 4 mm to 34 mm lump size. A mid range lump size ore was identified as the preferred material to use for wear testing. This decision was based on the specific ore type maximum lump size of 15 mm as required for the wear test. The wear test apparatus used cannot provide conclusive results with the larger lump sizes of 34 mm and thus smaller sizes are used. Guidance on which ore samples to take was given by the external consultants tasked with performing the test work.

The test work is divided into two sections. Firstly the flow test work is carried out on the finer material with a higher clay content known to have bad flow angles. Included in the selection of fine materials is a sample of the scraper dribblings. This is the material scraped off the belt underneath the head pulley. Secondly, the wear tests were conducted on 15 mm samples as explained above.

A few common liners were selected for testing. These liners are shown in Table A. Some of these liners are known for their specific purpose and characteristics. Polyurethane is known to have a very good coefficient of friction and will, therefore, improve the flow of material. This material does, however, wear out quicker in high impact applications. Therefore, it is only considered for use inside the dribbling chute.

As can be seen from Figure 37 in section 4.3.2, the dribbling chute will only see scraper dribblings from the primary and secondary scrapers. It is protected from any main stream flow of material by the start up chute. This makes the polyurethane liner a prime candidate for lining this section of the chute.

Table A: *Material tested vs. liner type*

	Flow Tests				Wear Tests	
Liner	Fines 1	Fines 2	Fines 3	Scraper Dribblings	Coarse 1	Coarse 2
Chrome Carbide	×	×	×		×	×
VRN 500	×	×	×		×	×
94% Alumina Ceramic	×	×	×	×	×	×
Poly Urethane				×		

FLOW TEST WORK

The fines 1 sample was tested at three different moisture contents of 3.6%, 4.1% and 4.7%. This is 70%, 80% and 90% of saturation moisture respectively. No noticeable difference was observed in the wall friction angles. Therefore, the fines 2 and fines 3 samples were tested at 80% of saturation which is 4.2% and 4.3% moisture content respectively.

Test work showed that the minimum chute angle required for flow increased as the impact pressure increased. Chute angles were measured up to impact pressures of about 8 kPa. The worst chute angle obtained was 62°. This means that no angle inside the chute should be less than 62° from the horizontal.

The scraper dribblings were tested at a moisture content of 12%. This material possesses the most clay content and, therefore, has the worst flow properties. During testing of this material, water was added to improve the flow. At an impact pressure of 0.3 kPa the minimum chute angle drops from 62° to 56° when adding a fine mist spray of water.

WEAR TEST WORK

As stated in chapter 4, wear tests were conducted on the chrome carbide overlay, ceramics and VRN500. The results of these tests are shown as non dimensional wear ratios of mm wear/mm travel of bulk solid sliding on the wear liners coupon at a given force. Test results shown in Table B indicate that the chrome carbide will have about 1.85 times the lifetime of 94% alumina ceramics. The VRN500 liner will wear about 6 times faster than the 94% alumina ceramics at the same force.

Table B: *Wear ratios of liners at two different pressure ranges*

Ore / Wall Coupon	65 kPa	163kPa – 173 kPa
Coarse 1 on 94% Alumina Ceramic	9.0 E-9	3.7 E-8
Coarse 1 on Chrome Carbide	8.7 E-9	2.0 E-8
Coarse 1 on VRN500	9.1 E-8	2.4 E-7
Coarse 2 on 94% Alumina Ceramics	3.8 E-9	2.2 E-8
Coarse 2 on Chrome Carbide	5.5 E-9	1.5 E-8
Coarse 2 on VRN500	6.6 E-8	2.5 E-7

LINER SELECTION

The lifetime of the liners is not the only criteria. Maintainability and cost are also factors that must be considered. Chrome carbide seems to be the liner of choice for this application. However, the specific type of chrome carbide tested is not manufactured locally and the imported cost is approximately three times that of ceramics.

VRN500 is slightly cheaper than ceramics and can easily be bolted to the back plate of the chute which makes maintenance very simple. Ceramics are, however, widely used on the facility and the maintenance teams are well trained for this specific liner. Therefore, 94% alumina ceramics is chosen for this application.

APPENDIX B: CHUTE CONTROL PHILOSOPHY

SPOON IN THE OPERATING POSITION

For the spoon to be in the operating position the moving head must be over that specific spoon and the feeding stockyard conveyor must be running. This means that material will be fed through the chute. In this case the spoon needs to be in the operating position to prevent spillage.

However, when the chute is in the operating position and the feeding conveyor trips for any reason, the actuated spoon section must not move to the non operating position. If the spoon position feedback fails then the system must trip and the spoon must remain in its last position. The downstream conveyor must also fail to start with this condition.

SPOON IN THE NON OPERATING POSITION

As a rule the spoon needs to be in the non operating position when the moving head, on that specific stockyard conveyor, is in the purging position (position C). The reason is that when a stacker reclaimer is in stacking mode, any upstream stacker reclaimer can be reclaiming. The reclaimed material on CV #5 or CV #6 will have to pass underneath the actuated chute.

ACTUATED SPOON OVER CV #5

As an example for the movement of any actuated spoon on CV #5 the following are considered. When the moving heads of any of the stockyard conveyors are in position A and that specific stockyard conveyor is running then the rest of the actuated spoons over CV #5 must be in the non operating position. The following scenario provides a better understanding.

- CV #4 is running
- CV #4 moving head is in position A.

In this situation all the actuated spoons on CV #5, except underneath CV #4, must be in the non operating position.

ACTUATED SPOON OVER CV #6

As an example for the movement of any actuated spoon on CV #6 the following are considered. When the moving heads of any of the stockyard conveyors are in position B and that specific stockyard conveyor is running then the rest of the actuated spoons over CV #6 must be in the non operating position. The following scenario is similar to 4.5.3 but explains the control philosophy for the moving head in position B.

- CV #2 is running
- CV #2 moving head is in position B.

In this situation all the actuated spoons on CV #6, except underneath CV #2, must be in the non operating position.