DEM – Simulation of Conveyor Transfer Chutes

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Conveyor transfer stations are critical parts within the conveyor track. The material has to be guided from the oncoming conveyor to the following transport system. This is realized by using tranfer chutes, which have to be designed in such a way that dust, noise and wear are minimized. One of the main tasks of the chute design process is to avoid blockages where the flow is hindered or obstructed due to build up of material in the chute.

The investigations leading to a proper chute design are carried out by experimental tests in the laboratory, with the aid of computer simulation programs. The presentation shows every single step to reach the optimum chute design for each application.

Keywords: belt conveyor, transfer chute, material behaviour, computer simulation.

1. INTRODUCTION

At transfer points of belt conveyors chutes are needed to guide the material flow in the direction of travel of the discharge belt conveyor and also provide an optimal solution to overcome any existing vertical transfer height.

In Figure 1, on the left, a transfer point is shown where an oncoming belt conveyor drops the material without any change of direction onto a following conveyor. To protect the inside wall of the chute an impact plate (18) is installed.

At the second transfer point (on the right in Figure 1) the direction of the material flow is changed by approximately 90º (with the flow of the material now either into or out of the page).

At these transfer points it is very important to guide the material in such a way, that the material drops in the centre of the belt. Material loading away from the belt centre is one of the main reasons for belt misalignment.
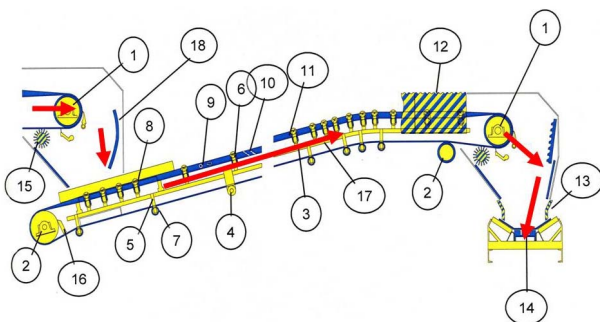

Figure 1. Transfer chutes

Some types of transfer stations are shown in the next figures. In Figure 2, a transfer station is shown, where the material flow does not change direction. This type of transfer station can be seen very often in the mining industry. The blue housing, in Figure 2, has the task of

containing the dust and noise emissions and preventing their escape into the surrounding environment.

Figure 2. Transfer chute – material flow in same direction

In Figure 3, the material flow is guided around a 90° corner. The small picture on the right shows the inside of the chute. As mentioned before, centred belt loading is very important for proper belt travel and alignment of the discharge conveyor.
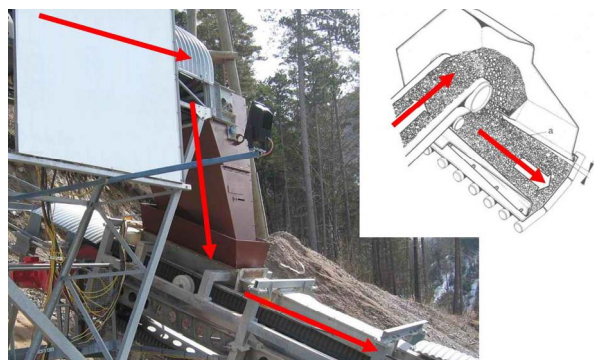

Figure 3. Transfer chute – material flow with changing direction

A more complex chute is shown in Figure 4. This is a variable path chute, which extends over a large vertical distance and divides the material flow into three diverted discharge points. The variable distribution is realized by butterfly valves, which are able to be open or closed inside the chute as the desired material flow dictates.
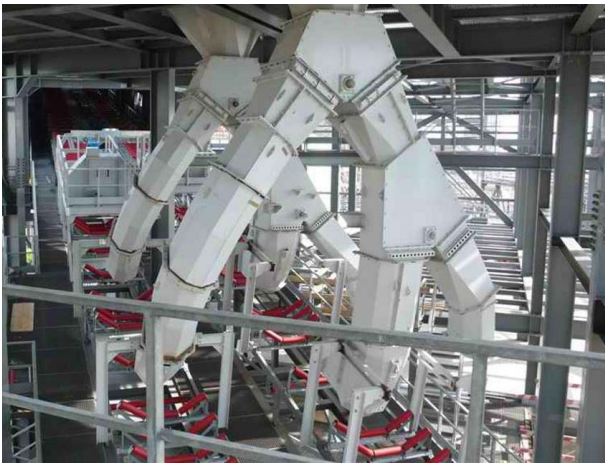
Figure 4. Switchable transfer chutes

In this type of chute the cross-section must be correctly designed, otherwise blockages such as plugging occur and the flow of the material is obstructed. Also packing is a serious problem in long chutes. If plugging or packing appears, it is very difficult to clean the chute and in preparation for further operation.

Similar long chutes designed to allow the variation of the horizontal and vertical angles, can be found inside of large stockyard equipment, such as stackers and/or reclaimers (Fig. 5).

Figure 5. Transfer chutes for varying vertical and horizontal angles of discharge belt

The optimization of chutes in Section 3 is related to such long chutes as depicted here in Figures 4 and 5.

The three basic types of chutes outlined above, are the rigid chute – with or without a change in material flow direction (Figs. 2 and 3), the variable path – or "switchable" – chute (Fig. 4), and the variable geometry – or "pivot" – chute which allows for adjustability in both the horizontal and vertical directions (Fig. 5).

If we optimize a chute, the material flow must be taken into consideration. Due to the material flow unwanted phenomena can appear which are mentioned in Figure 6. These are described below.

Demands of chute design:
- avoid plugging and packing on impact points;
  - choosing the right impact angle;
  - sufficient cross-section for material flow;
  - control of material flow;
- minimizing wear on liners;
  - avoid sharp changes of flow direction;
  - avoid creation of dust;
    - dust is created by mixing material with air therefore, material should always remain in contact with chute;

- concentration of material flow (small cross-sectional area);
    - material speed should be constant inside chute;
    - matching material flow at discharge point
    - airflow control inside chute;
- avoid spillage;
- minimization of material degradation;
  - ex. small angle between material flow and impact plate at impact point;
- load material on the centre of the discharge belt at a uniform rate;
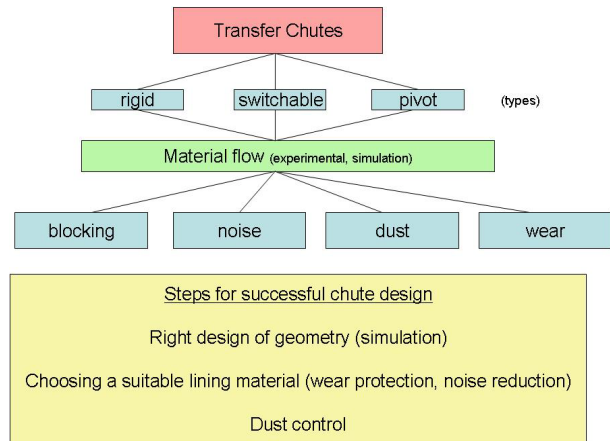- load the material in the direction of belt travel with same speed the belt is moving.

Figure 6. Transfer chutes

2. DISCRETE ELEMENT SIMULATION PROGRAM EDEM OF DEMSOLUTIONS

In installations already built and in operation, many problems occur regarding transfer cutes. This is because they are designed either by rule of thumb or by experience engineers gained over the years from different installations. The results are expensive repairs and costly maintenance. Each chute is unique and must be designed very specifically. Also, full-scale testing is not possible in most cases.

A useful tool in the design of optimum transfer chutes are computer-simulation programs based on the discrete element method (DEM) in connection with computer aided design (CAD). Many simulation programs for chute design are on the market, like Chute Maven, Chute Analyst, EDEM from DEMsolutions as well as others.

With the development of increasingly powerful computers, DEM simulation becomes more and more interesting and applicable for science and industry. References [1-7] show a small outline of this development.

In these simulation programs, particles of real bulk solids are replaced by geometrical shapes like marbles (spherical particles – discrete elements) with different diameters. The interaction of each single spherical particle to the neighbour particles, respectively the chute liners is calculated. It is also possible for the simulation to create more complex material geometries by combining a number of spherical particles to one piece as shown in Figure 7. The combined spherical particles

can be covered by a wrapping surface to receive particles with special optical appearance. These surfaces have no influence on the calculations because only the interaction between the spherical particles is taken into consideration.
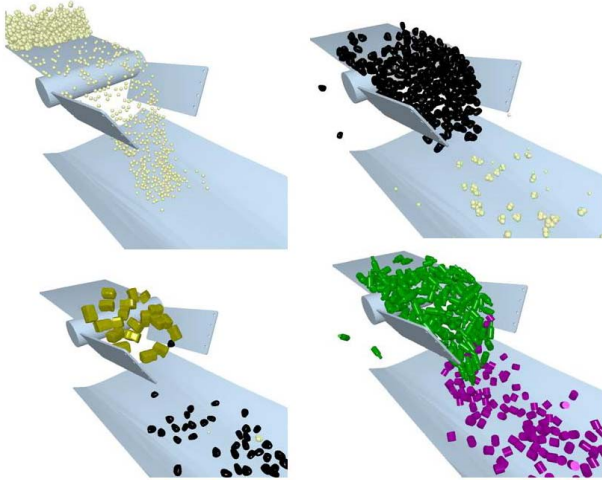

Figure 7. Particles in different shapes and colour

The result of the calculation can be a video clip which shows the movement of the particles within the chosen boundary geometries of the chute. In Figure 8, a result of a bulk material simulation can be seen.
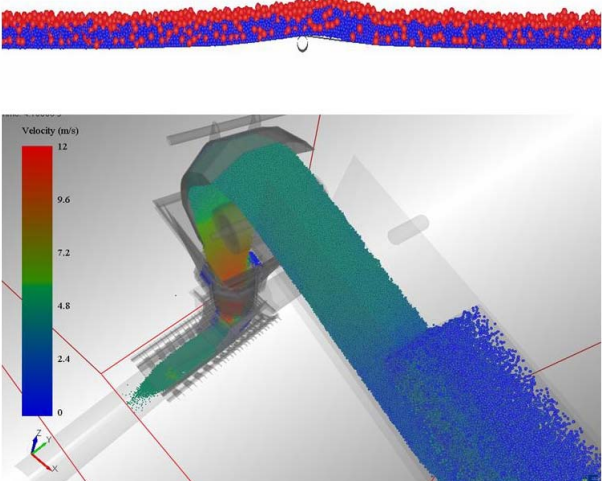

Figure 8. Flow behaviour of all kinds of bulk material

The computer program is also able to calculate forces, tensions, vectors of movement etc. In this paper we do not look at these parts of calculation.

When designing a chute, all the aforementioned demands have to be taken into consideration to achieve the following goals.

Goal is an optimum material flow with
- constant speed;
- low impact;
- low wear on chute lining and at discharge location;
- low dust emission;
- low noise emission.

The simulation has to look at following components:
- feeding conveyor;
- impact plates and liners;
- rock box;
- dividing chute;
- chute profile;
- discharge conveyor.

To reach these goals the simulation program needs the following input data:
- geometry – (CAD) data of the transfer chute;
- parameters of the bulk material (grain size, density, friction between particles, shear modulus, Poisson's ratio, cohesion, coefficient of restitution, etc.);
- flow capacity, speed and geometry of the conveyor's;
- friction coefficient between bulk material and chute components;
- etc.

In the event that all these data are not available in the beginning experimental tests with the bulk material and the chute inside wall material in the laboratory are necessary and significant for useable simulation results.

3. EXPERIMENTAL TESTS

The above mentioned material parameters must be investigated with experimental tests in the laboratory.

To obtain comparable test results, the test facilities as well as the test procedures must be standardized. The chair of Conveying Technology of the University of Leoben, Austria is working on this project at the moment.

For example, the investigation of the friction coefficient between the bulk material and the chute liners shall be shown.

With the test facility in Figure 9, the friction coefficient between the bulk material and the chute liners can be measured. The measurement can be done for each material depending on bulk material pressure and material velocity.
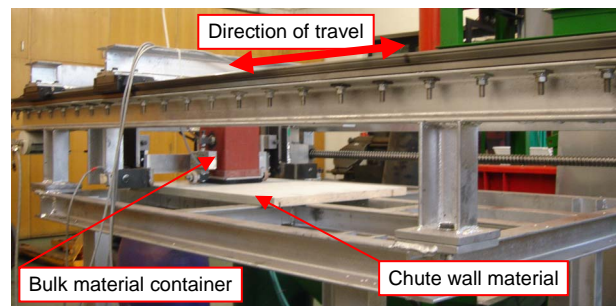

Figure 9. Experimental tests – friction coefficient between bulk material and chute components

The container is filled with bulk material. It is possible to define the load on the material. The container moves in horizontal direction over the chute plate material with adjustable speed. A load sensor measures the horizontal force which is set into relation to the vertical force of the bulk material.

This leads to a coefficient of friction result that acts as an input parameter for the simulation program. The parameter gets adjusted by several simulations until the simulation result matches with the experimental test.

This procedure is necessary because the real material is replaced in the simulation program by spherical particles.

Figure 10, shows a comparison between a laboratory test and the result of a simulation program. From the

laboratory test a video is taken and gets compared on the computer screen with the simulation result. If the videos do not match the input parameters are adjusted until the results are the same. This enables the calibration of the simulation program, allowing the successful simulation of the complete chute system.
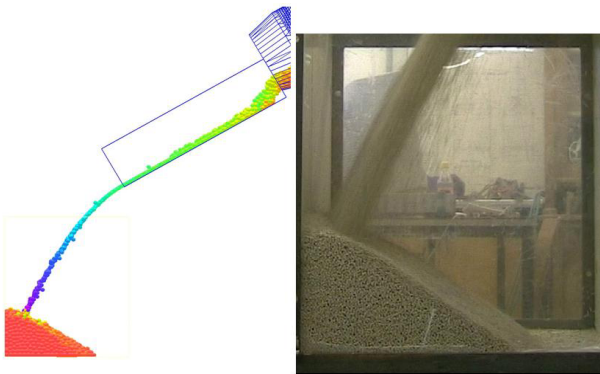

Figure 10. Comparison of simulation (left) and laboratory test (right)
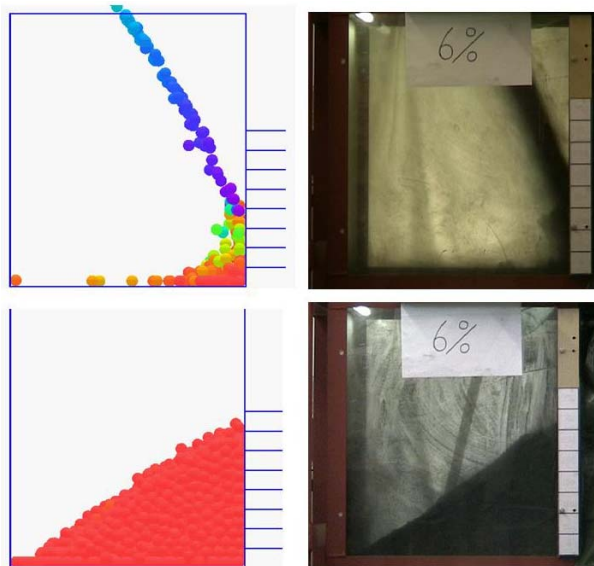
Figure 11, shows a similar procedure.

Figure 11. Comparison of simulation and laboratory test

The behaviour of a coal sample with 6 % moisture content is tested in the laboratory and the results are compared with the computer simulation.

In Figure 12, the experiment of Figure 11 continues by opening a discharge point. The material flow is observed and a video is taken for the next comparison with the simulation result.

These fundamental tests are necessary to find the right input parameters for the simulation program.

If all comparisons between experimental tests and simulations produce favourable results, the simulation of the entire chute system can be undertaken. Now the geometry data of the delivering conveyor and the discharge conveyor, the belt speeds and capacities and the space limitations inside the stacker or reclaimer are loaded into the computer program and the chute design can be modelled and simulated.

After several simulations, the chute model approaches an optimized design with regards to the throughput, wear, noise emission and dust emission.
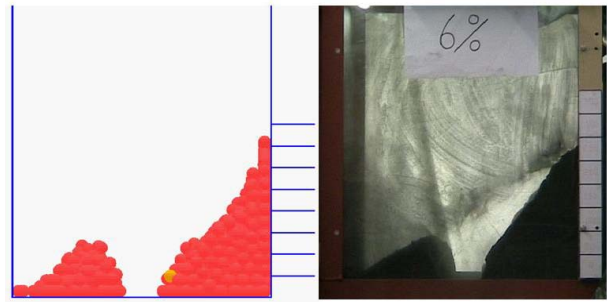

Figure 12. Comparison of simulation and laboratory test – geometry of material after opening the discharge point

For further confirmation of the optimized chute design, in some cases additional laboratory tests with a scaled chute model are undertaken. (Figs. 13 and 14).

Figure 13. Scale model for comparison with simulation

Figure 14. Scale model for comparison with simulation

Therefore a scaled model of the chute is built using plastics. These tests can lead to an additional improvement of the chute and the engineer can make corrections in the geometry input data of the program.

Figures 13 and 14 show scaled models of transfer chutes made of clear plastics for further laboratory tests.

If the oncoming belt conveyor is operated at varying belt speeds, the parabolic trajectory is also investigated by experimental and numerical methods.

The results lead to a chute design which matches with the material flow. Also the optimum location of

impact point and angle of the impact plates are found by conducting these analyses.

Figures 15 and 16 show a study of belt conveyors, where belt speeds and material flow are varying during operation. The chute has to be designed in such a way, that every operating mode can be handled without any functional problems.
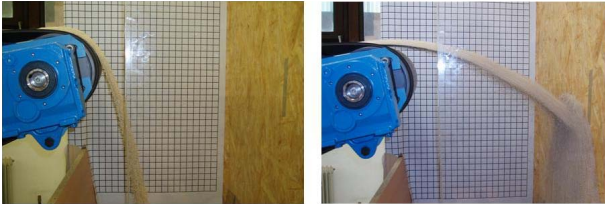

Figure 15. Experimental test – parabolic trajectory
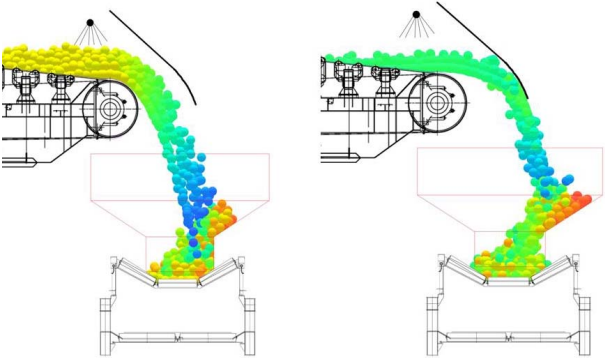

Figure 16. DEM-method – parabolic trajectory

The result of a computer simulation is a video clip, where the particles change their colour, depending on the speed. So it is easy to determine the material speed in every section of the chute.

In Figure 16, the geometry of the chute and the position of the impact plate are designed in such a way that the discharge conveyor gets loaded in the centre in all operating modes. Also material built up, wear, noise and dust emission are also minimized.

4. OPTIMIZATION OF BELT CONVEYOR TRANSFER CHUTES

In this section a few examples of transfer chute optimization carried out by the chair of conveying technology of the University of Leoben, Austria are shown.

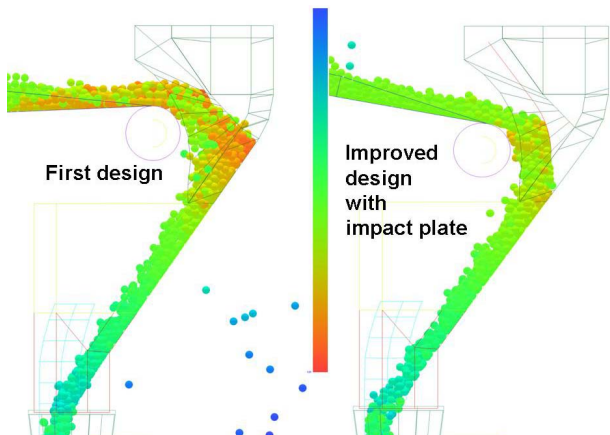Figure 17 shows the first design of a chute, which is checked by the simulation program.

Figure 17. DEM-method – checking a first design

After input of geometry data, belt speed, flow capacity, and all parameters measured in the laboratory it could be seen that a material build-up occurs at the beginning of the chute which led, after a short time, to plugging of the chute.

The installation of an impact plate could solve this problem. Figure 17 on the right shows the result of the improved chute design. The material build-up is eliminated and the speed of the material flow is almost constant over the entire length of the chute. This is the aim of all chute design. Also an optimum airflow inside the chute is realized, which keeps the dust emission very low.

A further study is shown in Figures 18 and 19. The task was to check an existing chute, which is currently designed and dimensioned for a material capacity of 4000 t/h. The aim was to establish if an increase of the capacity up to 6500 t/h is possible.
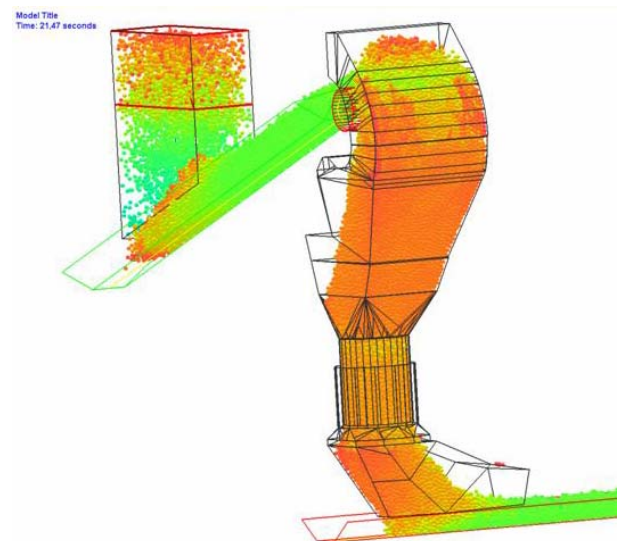

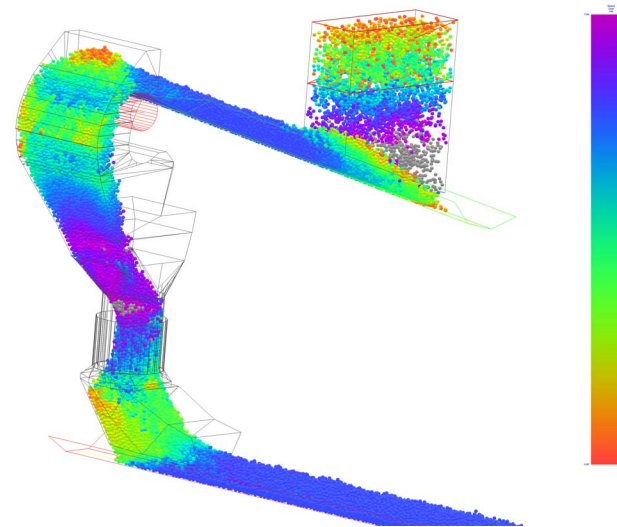**Figure 18. DEM-method – analysed chute at different capacities and belt speeds**

Figure 19. DEM-method – analysed chute at different capacities and belt speeds

The critical cross-section prior to the discharge point is located inside the swivel of the reclaimer. Due to this geometrical limit the cross-section can not be designed larger and the chute can handle the material flow only at

dry condition. An increase in moisture content of the material leads immediately to a material build-up followed by a plugging of the chute.

Also, with a dry material present through the chute, the belt speed of the discharge conveyor must increase to prevent built-ups at the discharge point.

This information is very important for the operator of the equipment. Now the limits of the chute are known, the operator is able to adjust the belt speeds or can react in an appropriate manner if problems occur. The operator now has the knowledge and ability to ensure problem-free operation.

The chute in Figure 20 has been optimized in consideration of geometry data, capacity limits, speed distribution, impact and airflow for dust control.
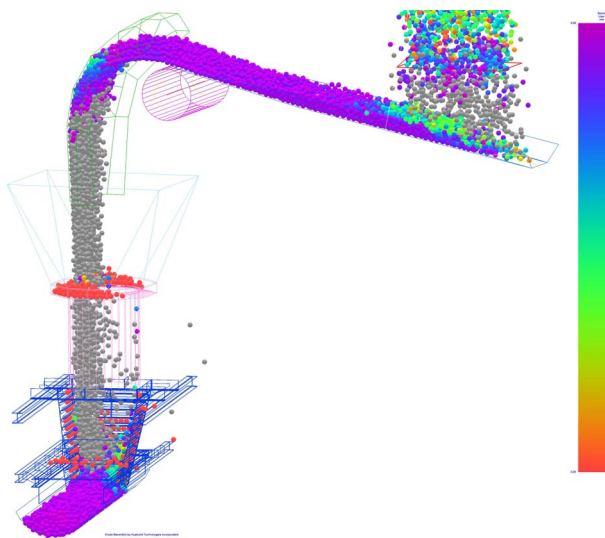

Figure 20. Analysis of chute at different capacities and belt speeds

The swivel of the chute, which is located inside a reclaimer, was the critical section of the material throughput because the maximum cross-sectional area was limited by the surrounding stacker construction, the chute geometry has to be changed in a way that the material speed in this cross-section became as high as possible.

Due to the higher speed of the material, an air flow is created which eliminates the dust emission. The upper section of the chute matches with the parabolic trajectory and keeps the impact angle on the liners as low as possible.

Figure 21 also shows a result of a simulation where the limits of the chute are investigated.

It can be easily seen that the already existing chute is not able to handle a material capacity of 14,666 t/h and must be modified or even re-designed for the next reclaimer.

The design for the new chute started out from the old chute design, because the geometrical limits around the chute given by the reclaimer were the same.

The optimization started at the top of the chute in order to increase the material speed. The first step was to match the upper chute section to the parabolic trajectory as closely as possible considering the geometrical limits.
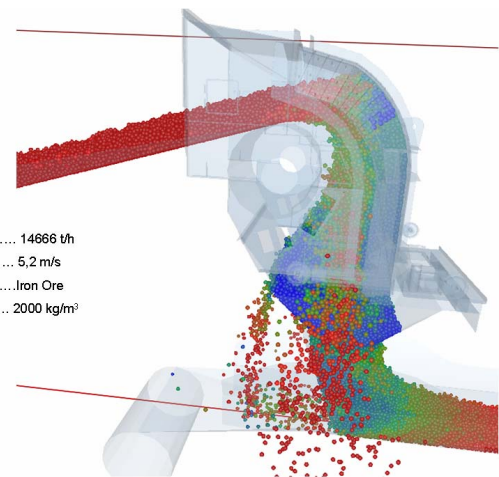
Daqta:
Capacity .... 14666 t/h
Belt speed .... 5,2 m/s
Material ....Iron Ore
Density .... 2000 kg/m³

Figure 21. Analysed chute at desired capacity and belt speeds using existing geometry

The next steps were the middle section followed by the discharge section which leads the material onto the discharge conveyor. At the discharge location it is important to guide the material in such a way that material speed matches with the belt speed. An optimum result is shown in Figure 22.
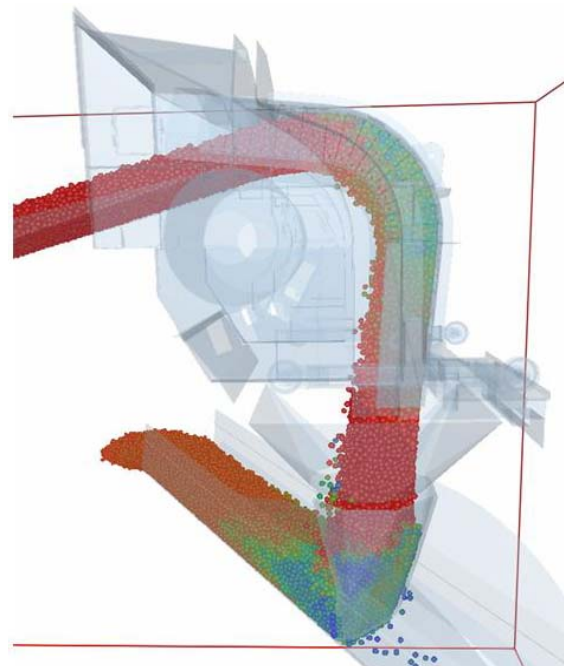

Figure 22. Improvement of chute geometry to eliminate functional problems – material flow in new designed chute after optimization

At the inlet of the chute, an insignificant decrease of material speed occurs due to the limited space inside the reclaimer. The compromise is not bad because wear is lowered this way.

The speed distribution through the chute is, on average, constant and at the lower end of the chute an acceptable material build-up is created, which compensates for the impact conditions and minimizes wear on the discharge conveyor.

The example in Figure 23 shows the optimization of a chute using a rock box instead of an impact plate. The rock box shall minimize wear inside the chute and guide the material flow in the right direction.
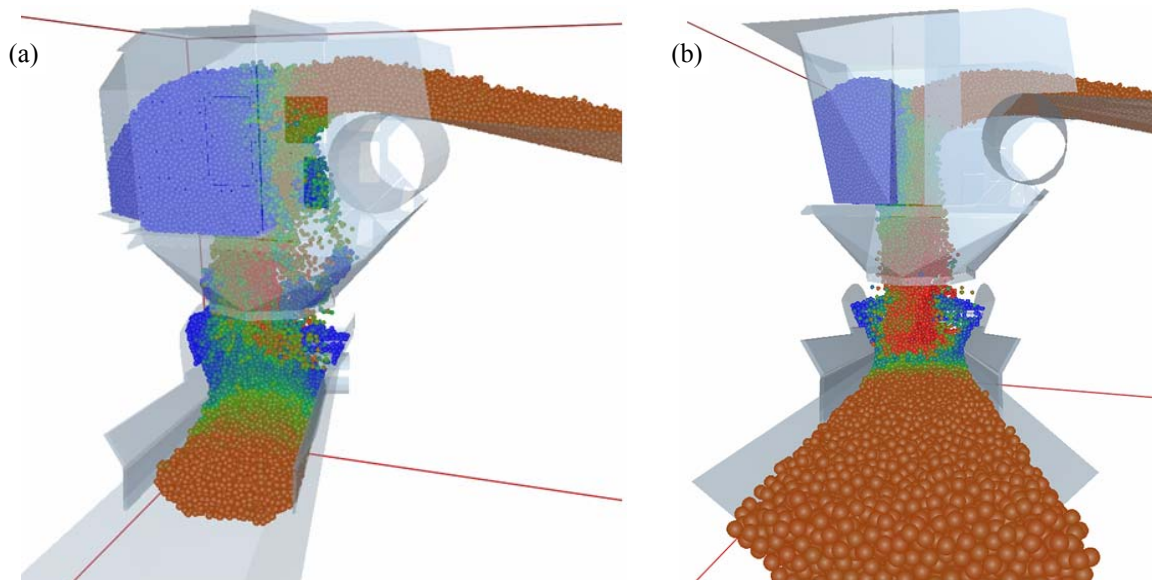
Figure 23. Improvement of a chute with rock box to eliminate functional problems and wear: (a) before improvement and (b) after improvement

In Figure 23a, a first design can be seen, where the material creates an unnecessarily large material build-up.

Due to this material build-up wear is transferred from the upper part of the chute to the lower part. Also, the material flow is eccentric as well as not being concentrated in a uniform stream. As the impact is not centred on the discharge belt, the result is the problematic misalignment of the belt.

The re-design of the rock box (Fig. 23b) leads to a smaller material build up, as well as compact and even material flow and therefore a centred belt loading.

Chute discharge sections not designed specifically and exactly according to the requirements of a system are consistently the reason for misalignment of the discharge belt, which in turn creates big problems during operation.

5. CONCLUSION

Transfer stations between belt conveyors are commonly occurring throughout industry. They are components of conveyor systems where problems such as noise and dust emissions, wear and plugging can easily occur. The designing engineer must take these factors into consideration and adopt designs to avoid these problems occurring in field operations. Repairs later in the stockyard or onsite are very expensive and sometimes even impossible.

In earlier days the chute design was based in most cases on rule of thumb or on the experience of the designing engineer. Nowadays, computer simulation programs are used and assist the designer in creating an optimum transfer chute which guarantees a safe and trouble free operation.

Simulation programs like the hereby adopted DE – Programs of DEMsolutions and Hustrulid Technologies, Inc. allow the design and commissioning of entire chute systems on the computer prior to installation.

The most significant influence of a useful simulation result is the exact knowledge of the input parameters. Investigations and tests in the laboratory are essential to get the right input parameters, allowing for accurate calibration of the modelling software. It is crucial that these laboratory tests be undertaken for every bulk material and chute system in isolation so as to avoid problems after the installation of a designed system.

Presently the experimental testing procedures undertaken to obtain values for these parameters are not fully independent.

It is the focus of current efforts to develop standardized measurement techniques, where all the parameters can be measured independently of each other. There still remains a large amount of research work necessary to achieve this goal.

As long as the parameters can not be measured independently, some of the parameters must be estimated, which can lead to results not approaching the reality. This is undesirable.

Nevertheless, a good way to get results that approach reality are the comparison studies between laboratory tests and computer simulations like the examples presented here in section three of the paper. Taking this approach, the accurate calibration of the modelling software is possible and results are significant and meaningful.

In the near future, it is anticipated that standardized methods for parameter investigations will be available. Combined with test simulations all unnecessary risk in chute design and simulations will be eliminated.

The results of the presented chute simulations and optimizations are meanwhile confirmed by the trouble-free operation of constructed installations which are already in operation for a period of several years.

REFERENCES

[1] Nordell, L.K.: Palabora installs curved transfer chute in hard rock to minimize belt cover wear, Bulk Solids Handling, Vol. 14, No. 4, pp. 739-743, 1994.

[2] Zhao, D., Nezami, E.G. and Hashash Y.: Three-dimensional discrete element simulation for granular materials, Engineering Computations, Vol. 23, No. 7, pp. 749-770, 2006.

[3] Qiu, X. and Kruses, D.: Design of conveyor chute using discrete element method, in: *Proceedings of the Fourth U.S. National Congress on Computational Mechanics*, 08-10.08.1997, San Francisco, USA.

[4] Herzog, M.: *Untersuchungen zur Verbesserung der Schüttgutübergabe zwischen Gurtförderern*, Thesis, Technische Universität Dresden, Dresden, 1999.

[5] Kisters, P. and Gröger, T.: Modifikation einer übergabeschurre zur Staubreduzierung mit hilfe der diskrete elemente simulation, in: *Proceedings of the 10. Fachtagung Schüttgutfördertechnik 2005*, 28-29.09.2005, Magdeburg, Germany.

[6] Nordell, L.K..: Particle flow modeling: Transfer chutes and other applications, in: *Proceedings of the BELTCON 9 International Material Handling Conference*, 1997, Johannesburg, South Africa.

[7] Roberts, A.W., Wiche, J.S., Ilic, D.D. and Plint, S.: Flow dynamics and wear considerations in transfer chute design, in: *Proceedings of the ICBMH'04 – 8th International Conference on Bulk Materials Storage, Handling & Transportation*, 05-08.07.2004, Wollongong, Australia.

ДЕМ – СИМУЛАЦИЈА ТРАНСФЕР ЛЕВКОВА КОД ТРАНСПОРТЕРА

Франц Кеслер, Михаел Пренер

Трансфер станице код транспортера представљају критичне делове на путањи материјала. Материјал се води од долазног транспортера до следећег транспортног система. Ово се реализује помоћу трансфер левкова, који треба да се тако пројектују да се смањи прашина, бука и хабање. Један од главних задатака у процесу пројектовања трансфер левка је да се избегну блокаде на местима где је ток материјала ометен или закрчен услед нагомилавања материјала у левку.

Истраживања која воде ка правилном пројектовању левка су спроведена експерименталним испитивањима у лабораторији као и помоћу рачунарских програма за симулацију. Рад приказује сваки појединачни корак ка добијању оптималног решења конструкције трансфер левка и то за сваку примену.