MODERN ORE TRANSFER CHUTE & BELT FEEDER DESIGNS DEVELOPED FROM DISCRETE ELEMENT MODELING (DEM)

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ABSTRACT
Granular mechanics modeling of belt conveyor transfer chutes and belt feeder stockpile reclaim chutes is shown to produce a better understanding of pitfalls and insight into improving their designs. Characterizing ore flow physics, based on individual particle contact mechanics from Discrete Element Modeling (DEM), can lead to new treatment in: flow control recommendations, minimizing wear on belts and in chutes, reducing risks to belt, product degradation, dust emissions, and improving power demand. The new procedures, using analytic methods, are compared with present conventional practices.

1. INTRODUCTION
Belt conveyor transfer chutes have not been duly appreciated, nor has sufficient technology guided their design criteria. They control the safety and financial health of the conveyor belt in many critical areas of operation. Shown below in Fig. 1 are various modern configurations.

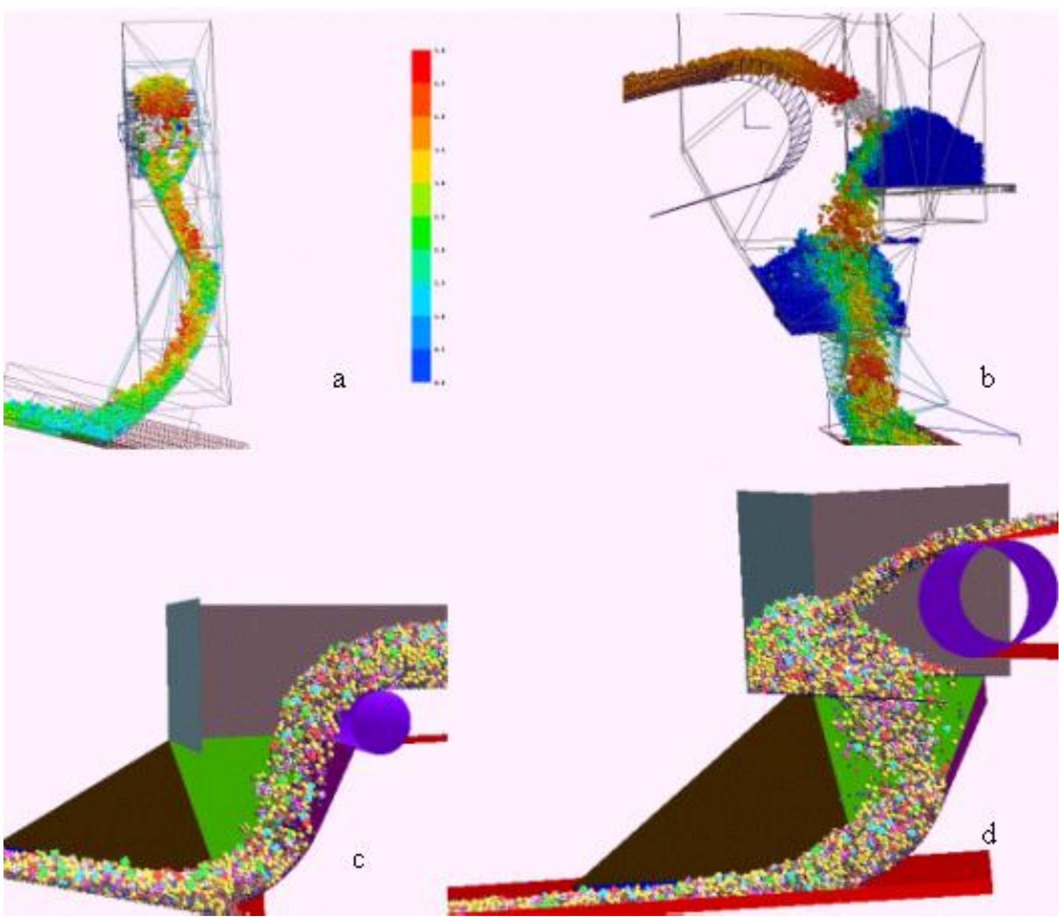

Fig. 1 - Variations on curve & rockbox transfer chute configurations and functions: a) Coal Lowering, b) 10000 t/h Hard Rock Lowering, c) 6000 t/h Hard Rock Belt Feeder, d) 8700 t/h x 6 m/s Hard Rock transfer

2. DISCRETE ELEMENT METHOD

Following is an excerpt from a paper by CDI's Dave Kruse introducing DEM (1).

The DEM method is the name given to a solution process by which the macroscopic properties of a system are determined by modeling its smaller individual components. Historically, the DEM method evolved from early molecular-dynamic algorithms and methods. The first DEM simulations used simple circular disks to represent individual particles or "discrete elements." This was entirely based on their mathematical simplicity. Contact algorithms for these particles were developed by Cundall & Strack (2).

The basic solution methodology behind the DEM method is as follows. First, all of the relevant particle forces and interactions are determined. Fig. 2 shows a simple type of contact model commonly used to model the behavior between two circular contacting particles. Simple springs, dashpots, frictional sliders, and directional latches are used. This type of 2D model can also be extended into full 3D when modeling spherical particles and other shapes.

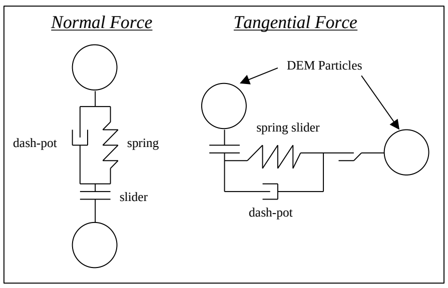

Fig. 2 – Simple DEM contact model

Once the individual particle contact forces have been determined, Newton's 2nd law is applied to determine translational acceleration and Euler's equation for angular acceleration.

Newton's Equation	Euler's Equation
$m\ddot{x} + c\dot{x} + kx - F = 0$	$I_1\dot{\omega}_1 + (I_3 - I_2)\omega_3\omega_2 - M_1 = 0$
$m\ddot{y} + c\dot{y} + ky - F = 0$	$I_2\dot{\omega}_2 + (I_1 - I_3)\omega_1\omega_3 - M_2 = 0$
$m\ddot{z} + c\dot{z} + kz - F = 0$	$I_3\dot{\omega}_3 + (I_2 - I_1)\omega_2\omega_1 - M_3 = 0$

Initially, only gravitational forces, particle-to-particles interactions forces, and particle-to-boundary forces were considered (as in Fig. 2 above). Current advancements include; cohesive & adhesive forces, breakage mechanics models and governing equations, fluid dynamic equations of state.

Simple and complicated shapes, including multiple particle groups or "clusters" simulate particle morphologies, as shown in Figures 3 through 5. Such clusters include: ellipsoids, clusters of spheres, polyhedrals, and many others.

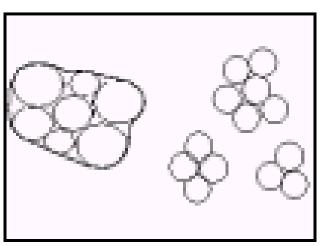

Fig. 3 - Disk clusters

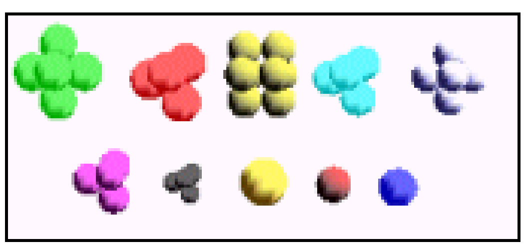

Fig. 4 - 1,4,6,8 group particle clusters

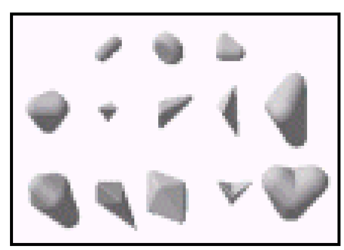

Fig. 5 - Higher order shapes

Boundary surfaces can be applied in a variety of different ways. For example, simple mathematical equations for lines and curved surfaces are often used. Other methods involve fixing or "gluing" particles to specific locations in space. Yet another technique is to use triangulate surfaces as shown in Fig. 6. The flexibility of triangular surfaces allows the users to generate almost any surface shape. Triangles are also very useful in the post processing stage to determine the impact and shear forces. Furthermore, triangles naturally lend themselves to easy visualization and computation.

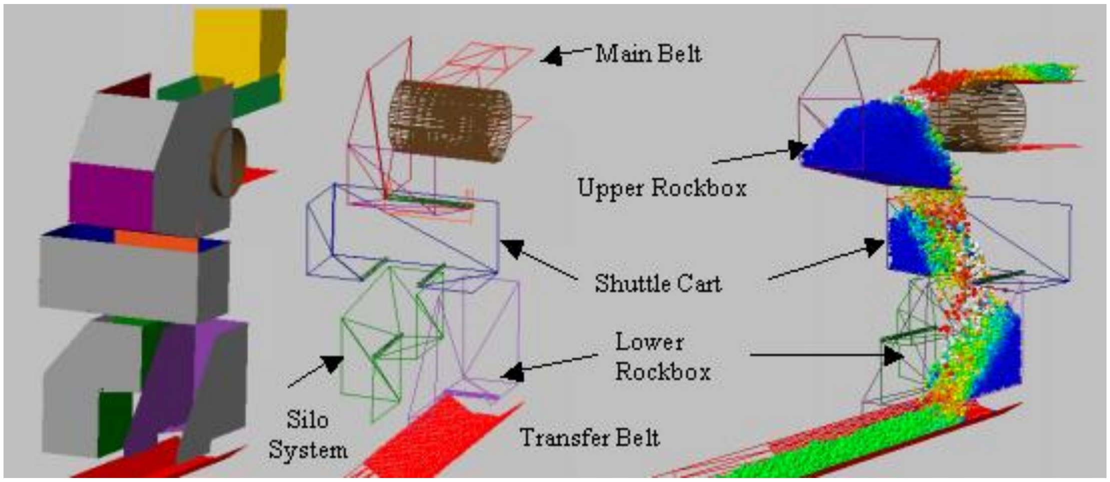

Fig. 6 – Dem boundary surfaces and material flow

Particle-to-boundary contact laws may be the same or different, from the laws governing particle-to-particle interactions. Additionally, individual particle types may possess their own material and other internal properties. For example, in the steel ball mill simulation, the steel balls would obviously have very different properties from ore.

This total flexibility, inherent to the DEM method, is by far its most tantalizing quality. By correctly modeling the individual properties of a system, its complex, and often-chaotic behavior, may be analyzed, altered, and improved. The potential applications in the mining industry alone are enormous.

3. CHUTE INFLUENCES ON OPERATION

Chute designs, using DEM, are improved in the following important ways:

a. belt wear life
b. product degradation and dust generation
c. puncture and ripping damage
d. belt capacity
e. spillage
f. pluggage
g. production losses
h. added maintenance resources and repairs
i. fugitive dust emissions
j. fire and explosion risks
k. noise emission
l. additional power
m. personnel health

Based on the value of the above 13 points, the degree of financial benefit or loss, due to chute performance, conceivably yields the second greatest return on the conveyor investment (2). It is, therefore, imperative to get it right.

4. BELT WEAR LIFE

At Palabora's copper ore mine in Northern South Africa, enhanced transfer chute geometry has substantially improved belt life (ref. 3,4,5, and Fig. 1c). Now, nine years since the first hard rock curved chute was applied, the belt is still in operation. Modified chute geometry has increased belt life 300%, over the original rockbox (3-year) life span. It is predicted to have a +20 year life span, based on eight years of cover wear measurements. Heavy metal and large sharp rock pieces are passed without measurable damage to the belt.

A 20-year wear life can now be set in the design criteria. No longer are +20 mm top covers required for wear or to protect tensile structure. Historical belt wear rates are now obsolete.

5. PRODUCT DEGRADATION AND DUST GENERATION

Product is degraded, or broken, by particle-to-particle collisions, and collisions between particles and boundaries. DEM can classify the collision energy that breaks particles and defines geometries that minimize breakage.

While iron ore value is lost due to breakage, coal carries a much greater risk from fire and explosions due to spontaneous combustion from fines generation (6).

A growing number of North American power plants are requesting dust-free transfer designs without the use of dust collectors and wet aerosols. These goals are being achieved through improved chute geometries that minimize particle velocity gradients and impacts. The concept is illustrated in Fig. 7.

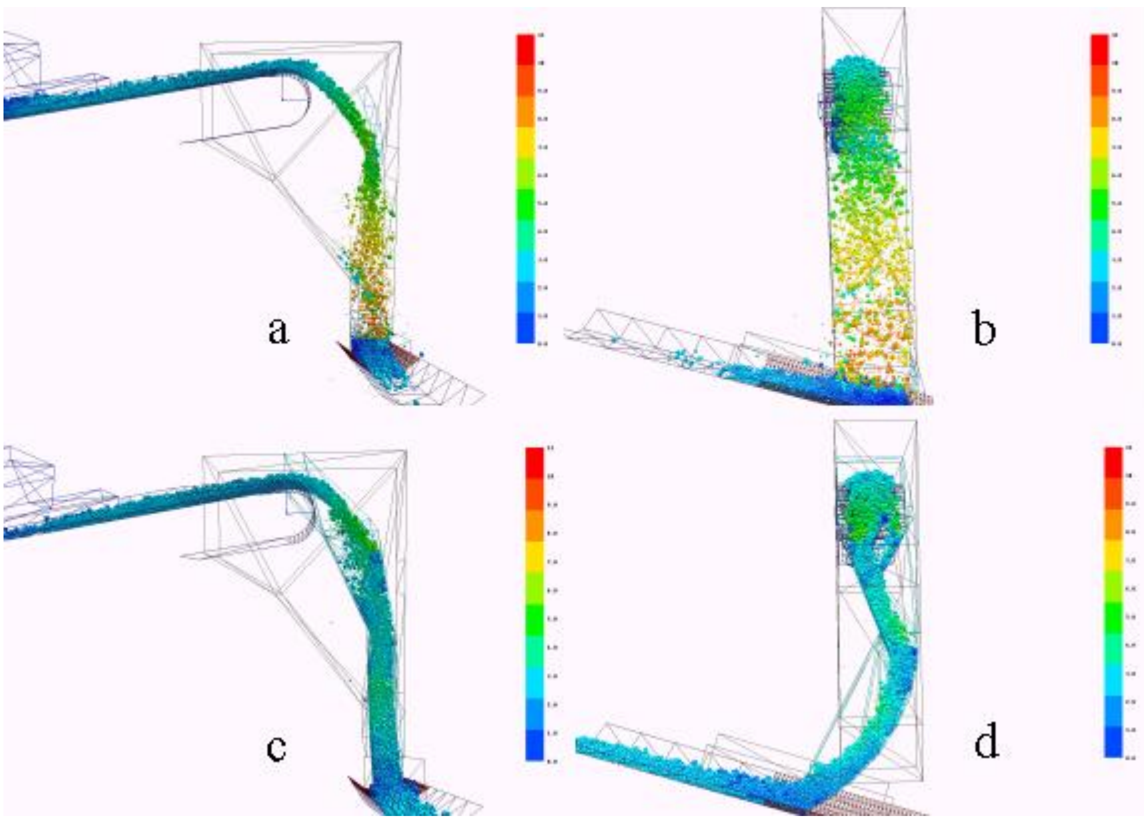

Fig. 7 - Coal Chute Transfer with 5-m drop: a) conventional chute side view, b) conventional chute front view, c) modified chute consolidating coal stream, d) front view – constant drop velocity

Figures 7a and 7b illustrate, through side and front views, a typical coal right angle transfer. Coal is discharged into a large hopper-like transfer chute, which has a 5-meter drop. We see two significant impact zones and note the coal's aerated and dispersed nature as its velocity reaches over 11 m/s. Coal impact on the belt is at a reverse angle causing significant turbulence and sliding shear work against the receiving belt.

Figures 7c and 7d show a modified chute with a compact flow stream and a lowering trough. The ore stream velocity is reduced to 4.5 m/s and is reasonably constant. The impact kinetic energy is reduced 83% to that of Figures 7a and 7b. Given that actual breakage is logarithmic (with change in intensity), the true benefit is greater than the 83% reduction. Very low breakage is achieved, due to the compact ore flow and constant velocity. Dust emission is significantly suppressed.

CDI measured coal degradation on a 9 km overland by placing size-selected coal into individual bags, sealed to contain moisture and unsealed to show difference in coal strength due to moisture loss during transport. Bags were placed on the overland feed point and removed after transport to the head end, as shown in Figure 8. The bag's contents were sieved for breakage before and after transport, and for sieve bias. Coal breakage, in the sub 30 micron size, was less than 0.7% over the 9 km route. This breakage study was made for a planned 75 km overland. On the same property, coal degradation was measured on a selected chute, similar to Fig. 7a. Ten repeat passes of coal yielded a consistent 1% shift in particle size reduction per pass. Today, power plant operators are asking for improvement guarantees to weigh benefits of proposed designs. DEM provides a means of measuring the proposed guarantee.

Fig 8. Above are two photographs of the test bags of sized coal.

6. SPILLAGE, BELT ALIGNMENT, AND CAPACITY LOSS

Spillage can occur from violent loading, off-center loading, and belt mistracking. Violent loading can dilate skirt seals, forcing leakage. Violent loading on inclines may not settle and spill when leaving the skirt zone, similar to Figure 7b.

Off-center loading heaps material to one side and it may not be contained once it leaves the skirt zone. Off-center loading causes lateral non-symmetrical thrust forces, which can push the incoming belt far enough off-center to cause spillage upon leaving the skirt zone.

CEMA, DIN 22101, and ISO 5048 specify that the belt capacity must include a free edge clearance. This clearance amounts to 6% of the belt width for each side of the wing rolls. The 6% figure is a long established value resulting from experience. Aside from belt slope, the figure accounts for a) load tracking error, b) lump containment, c) belt construction tracking error (rubber and steel), d) belt transition containment, and e) structural and idler alignment errors. Load tracking error should not vary with belt width. If this error is removed, by proper load centering, the capacity can be increased by a minimum of 5% on a 915 mm (36-inch) belt, and 11% for an 1829 mm (72-inch) belt. Here we assume a 100 mm lump and twenty degree surcharge angle.

Fig. 9 illustrates ore flow through a rock box ledge system that can cause spillage, capacity reduction, and misalignment. Flow discharge is shown to be asymmetrical to the axis of the receiving belt. This phenomenon causes:

a. Side thrust causing belt misalignment
b. Additional particle of belt turbulence and belt shearing action, increasing belt wear

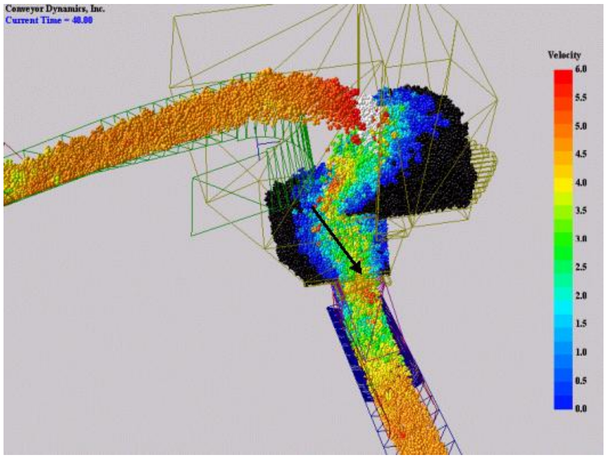

Fig 9. – Rock box ore drop and non-symmetric loading

Fig. 10 illustrates bin loading conditions; Fig. 10a is the client's first guess at proper upper chute placement to fill the bin and direct flow to the receiving conveyor. This demonstrates poor bin loading, under utilizing bin volumetric capacity. It also shows the receiving conveyor will not symmetrically load.

Figures 10b and 10c (top view of 10b) illustrates an improved upper chute design for proper bin loading. This achieves symmetric flow onto the receiving belt and eliminates direct drop belt impact.

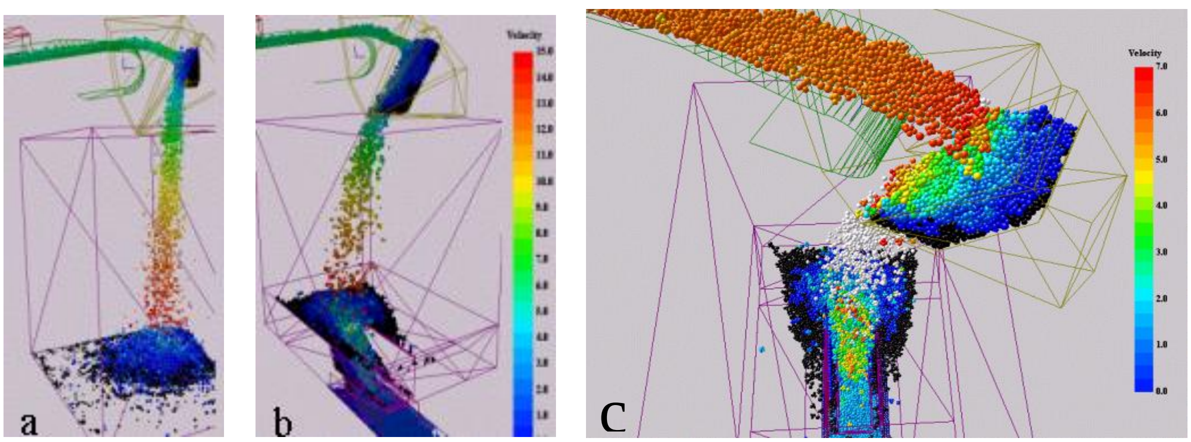

Fig. 10 – Ore directional loading into bin and onto conveyor and controlled directional drop into bin, positioned symmetric to receiving belt

7. PUNCTURE AND RIPPING DAMAGE

Lower curved chute geometry, often referred to as a spoon, can feed the product such that it does not allow a foreign object to gain sufficient force or leverage to penetrate the belt. DEM can define the geometry of the chute, and the motion of ore flow and foreign objects to achieve this goal.

There is a caveat. Some materials have a high cohesive strength and may not allow the best chute geometry to be implemented and thereby protect against penetration.

8. PLUGGAGE AND LOST PRODUCTION

Transfer chute pluggage cuts into plant production. Some of the types of pluggage can be anticipated with proper chute modeling. Fig. 11 illustrates questionable and proper flow control using DEM. Figures 11a and 11c show the stagnation zones in dark blue contrast. Figures 11b and 11d show that subtle changes in geometry, remove the stagnation zone. Further running of the DEM simulation caused pluggage of Figures 11a and 11c.

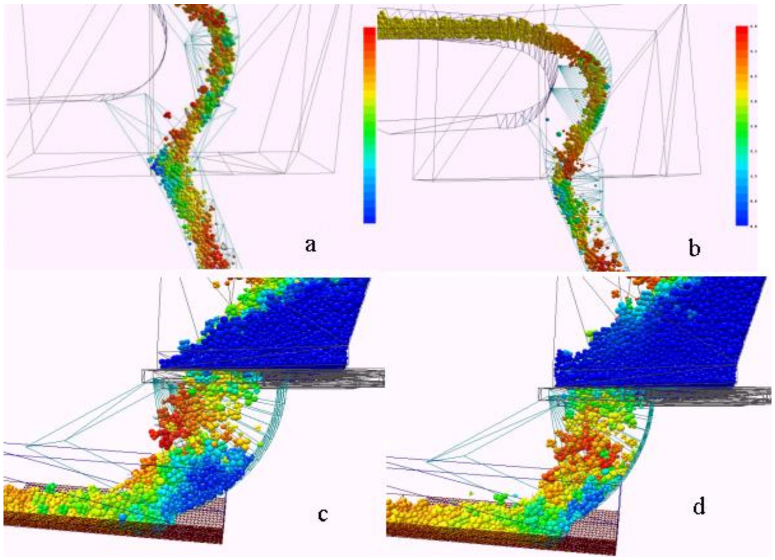

Fig. 11 – DEM simulation of stagnation flow on various chute surfaces: a) curved to flat surface, b) two upper curved surfaces, c*) curvature* too sharp, discharging at spoon end, large incident angle stalls ore flow, and d) proper curvature

Another example shows the sensitivity of friction and chute (spoon) curvature. This was taken from a DEM simulation case study shown in Fig. 12. The spoon's curvature and position lead to pluggage shown in Figures 12a and 12c. In Fig. 12a, with an ore internal friction at 0.5, flow proceeded, but a trace of stagnation can be seen. Raising the friction factor to f = 0.70, causes plug flow shown in Fig. 12c. Correcting the curvature and slope, while gently loading material onto the belt, did not produce pluggage beyond an ore internal friction of 0.7 simulated plugging in Fig. 12d.

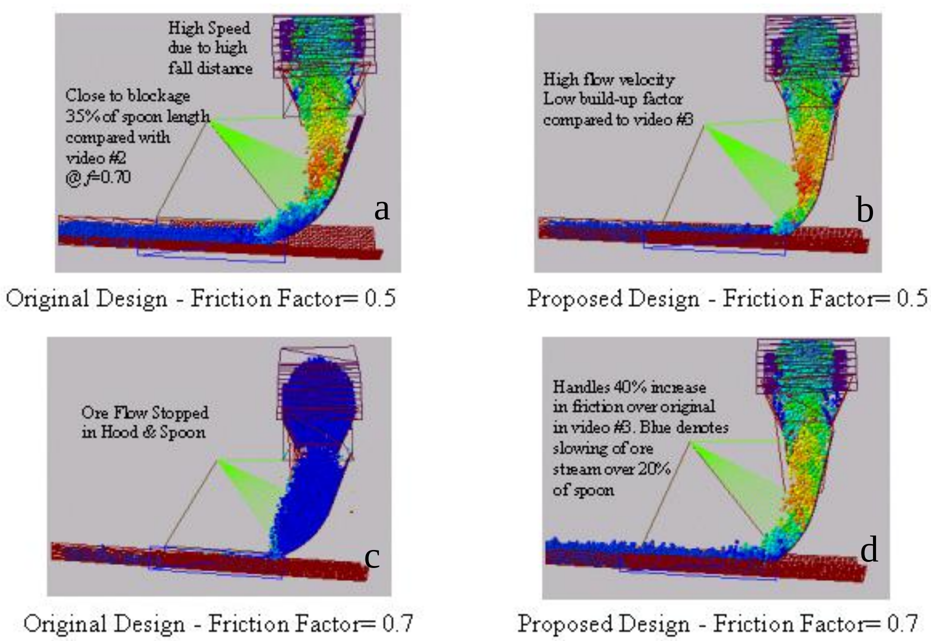

Fig. 12 – DEM simulation of curved spoon geometry and friction

9. BELT TRAJECTORY – CEMA vs. DEM

Much has been theorized about ore trajectories. DEM adds a new theoretical dimension. Fig. 13a illustrates a granular mix of clustered particles to simulate shear strength due to ore surface asperity. We illustrate in Fig. 13b the DEM trajectory path. Note, with a slow horizontal belt, the translational velocity starts before the ore reaches the pulley's vertical centerline. This means particles begin to move (and accelerate) before the predictions offered by most handbooks (CEMA, et al).

This is caused by the low stress state of particles in the flow zone. Assume the belt to be at rest. Then we anticipate the flow bed to recline to the angle of repose or about 40 degrees incline tangent to the pulley diameter as shown on Fig 13b. Fig. 13c illustrates the difference between the CEMA prediction and DEM result. Fig. 13d shows that DEM and CEMA come into agreement on fast moving belts, shown here at 6 m/s.

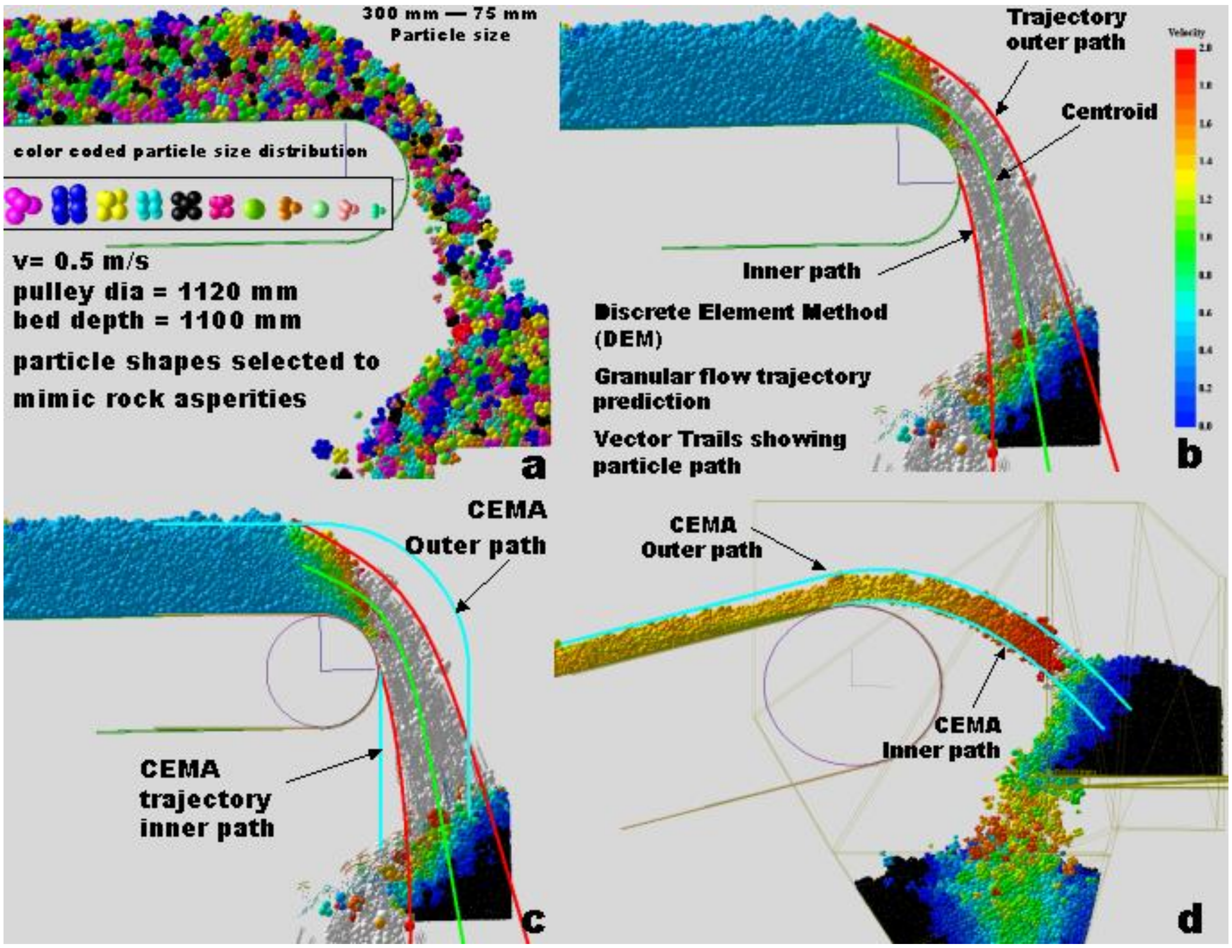

Fig. 13 - Ore Trajectory DEM vs. CEMA: a) granular sizes and shapes, b) DEM belt feeder trajectory, c) DEM vs. CEMA belt feeder trajectory, and d) DEM vs. CEMA high speed belt trajectory.

10. CONTROLLING RISKS OF FIRE & EXPLOSIONS

A 1984 North American study showed about 14% of all particulate emissions in coal fired power plants are from belt conveyors (6). A typical 500-MW plant produced over 70 tonnes of fine particle emissions in one year. Belt transfers and stockpiles produce most of this pollution.

A 1999 Edison Electric Institute study reported that 17% of fire losses, of over $250,000, were attributable to coal conveyors. They further reported:

a. Over the last 30 years, 10% of fires over $250,000 were from conveyors and conveyor applications
b. From 1989 to 1999, conveyors accounted for 13% of all fires. The rate of conveyor fires is increasing.

The preponderance of these accidents is from fugitive dust, fines, and spillage settling outside the chutes.

DEM simulation of coal flow can identify potential problems and guide engineers to “best practice” that: minimizes degradation that produces a dust product, minimizes gas turbulence that suspends dust, and directs and regulates flow in transfers that eliminate spillage. All 13 points of Section 3 are improved.

11. BELT FEEDERS

Many interesting belt feeder attributes can be studied using the DEM method. These include:

a. slot geometry above feeder to achieve mass flow
b. geometry flow enhancement at the discharge opening
c. particle size influence on flow behavior
d. power versus geometry
e. defining flow changes with ore rheology variables
f. belt wear

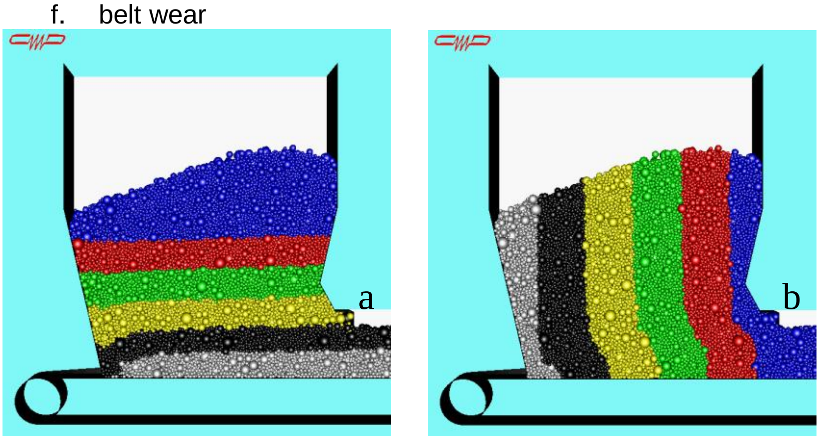

Fig. 14 – 14a and 14b show a DEM flow reclaim pattern colored particle zones.

Figure 15 illustrates DEM simulation of the product velocity gradient on a belt feeder. DEM will provide the theoretical test bed for optimization procedures for belt feeder geometries of the future.

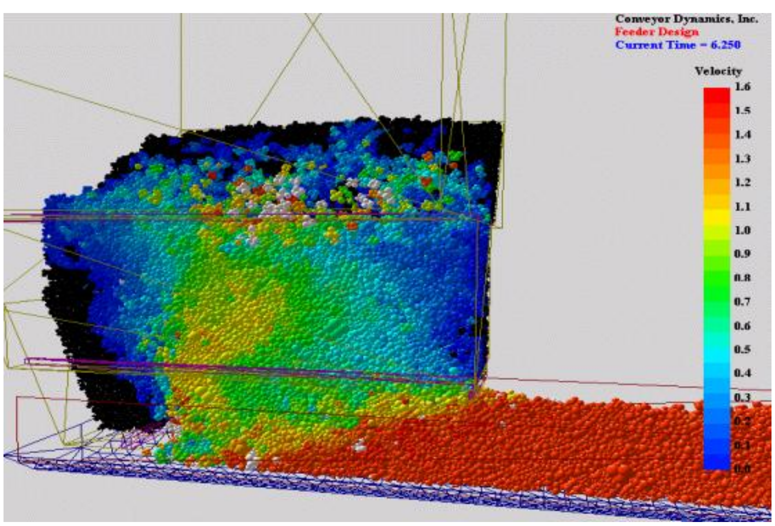

Fig. 15 illustrates DEM prediction of velocity gradients in a longitudinal cut of an ore section over a belt feeder.

12. NOISE EMISSIONS

DEM can define noise levels directly from the collision energy spectra, once the product flow and noise level are calibrated by tests against the simulated DEM energy spectra.

CONCLUSION

The discrete element method, combined with field measurements and past design experience, adds a new and extremely powerful tool available to engineers. Its implementation will improve performance in a variety of design areas, reduce operational risks, improve safety, and improve costs for the next generation of conveyors and the products they carry.

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