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CONTENTS

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PROCESSING

PERFORMANCE

SERVICE

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SUMMARY

Transfer points have historically been designed primarily for material throughput and secondly for fugitive material control. As dust control has become more important, the skirtboard extension is increasingly considered a dust control enclosure that can be designed for passive dust settling, for active dust collection or both. A study of transfer point geometry and its effect on nuisance and respirable dust was conducted with the goal of ether confirming current rules of thumb or developing new design criteria for bulk material passive dust control. SolidWorks FLOW computational fluid dynamics simulation software was used to compare the relative effectiveness of different discharge chute and skirtboard extension designs based on the percentage of dust particles between 1 and 100 μm in diameter that exit the skirtboards. The criteria used to judge the effectiveness was the average percentage of nuisance and respirable dust particles that exited the skirtboard enclosure compared to the number of particles injected into the discharge chute. The results clearly indicate that unless the skirtboard extension is properly sized, and multiple dust curtains are properly spaced and kept adjusted close to the bulk material profile, the performance in passive reduction of dust emissions is significantly reduced. Controlling the amount of air flow through the transfer is also critical. Sealing the area between the top and bottom runs of the discharge chute and minimizing bulk material free fall distances within the transfer chute are critical in reducing induced air flow. The more air volume through a chute, the faster the air velocity out of the chute, making it more difficult to settle the fine dust particles within the enclosure. And above all, the dust curtain systems must be accessible and maintainable to gain the benefits of passive dust suppression.

ZUSAMMENFASSUNG

Materialübergabestellen zwischen zwei Gurtbandförderern wurden bislang primär nach dem Massedurchsatz und sekundär nach Gesichtspunkten zur Kontrolle der Staubbelästigung ausgelegt. Da die Kontrolle von Staubemissionen wichtig ist, werden zunehmend die Abdichtungen an der Materialübergabe für die Staubkontrolle in Betracht gezogen, die für eine passive oder aktive Staubabscheidung oder zur Realisierung beider Funktionen ausgelegt werden können. Eine Studie zur Geometrie von Materialübergabestellen und Ihrer Wirksamkeit gegen Umweltverschmutzung und atmungsbelastenden Stäuben wurde mit dem Ziel der Bestätigung derzeit gültiger Gesetze und zur Entwicklung neuer Design-Kriterien für die passive Staubkontrolle bei Schüttgütern durchgeführt. Dabei wurde die Simulation Software SolidWorks Flow Computational Fluid Dynamics angewendet, um die relative Wirksamkeit verschiedener Übergabeschurren sowie die verwendeten Abdichtungs-Designs in Abhängigkeit vom Anteil der an den Abdichtungen austretenden Staubpartikel im Bereich von 1,0 bis 100 μm miteinander zu vergleichen. Das angewandte Kriterium zur Beurteilung der Wirksamkeit der angewandten Abdichtungen bildete der mittlere Prozentsatz der Belästigungen und einatmenbarer Staubpartikel, die aus den Abdichtungen der Materialübergabe austreten, verglichen mit der Anzahl der Partikel, die in die Übergabeschurre eingetragen werden. Die erzielten Ergebnisse sagen klar aus, dass, wenn die Abdichtungen entsprechend ausgeführt sind und die vielen Staubschleier korrekt aufgehalten und dicht am Profil der Schüttgutoberfläche entlang geführt werden, die Staubemissionen signifikant reduziert werden können. Als kritisch ist dabei die Kontrolle der Luftbewegung durch den Materialübergang zu bezeichnen. Zur Reduzierung der Luftbewegung wird deshalb beim Materialübergang zwischen zwei Gurtbandförderern eine Minimierung der Fallhöhe des Schüttguts angestrebt, da die Reduzierung der Luftbewegung innerhalb der Übergabeschurre schwierig ist. Je größer das durch eine Schurre geführte Luftvolumen ist, um so höher ist die Geschwindigkeit der aus der Schurre austretenden Luft, was die Abscheidung von feinen Staubpartikeln innerhalb der Materialübergabe erschwert. Andererseits müssen allerdings die Systeme zur Abscheidung der Staubschleier zugänglich und austauschbar sein, um die Vorteile einer passiven Staubreduzierung zu erreichen.

Passive dust control optimization for bulk material conveying

Passive Staubkontrolloptimierung für die Schüttgutförderung

1 Introduction

In the past transfer points have been designed primarily for material throughput and secondly for fugitive material control. As dust control has become more important, the skirtboard extension is increasingly considered a dust control enclosure that can be designed for passive dust settling, for active dust collection or both. Most engineering firms use the ACGIH Industrial Ventilation Handbook design criteria for active dust collection. The design rules for skirtboard extensions are based primarily on lump size and the length necessary for the bulk material to settle down into a stable profile. Despite an exhaustive literature search, no engineering confirmation or basis for the design of the skirtboard extensions was found. The origin of the skirtboard design rules and the ACGIH active dust collection recommendations seem to be based on New York City Health Department requirements for silica dust control in the 1930s.

A transfer point is similar to a gravity settling chamber, which are usually large enclosures used to pretreat gas streams prior to large dust collectors or electrostatic precipitators such as those found in coal fired power generation. These large-scale gravity settling chambers depend on relatively slow air speed without much turbulence. However, the air flow through a transfer point is almost always turbulent, so the design rules for gravity settling chambers do not directly relate to transfer point enclosure design.

The basic concept (› Fig. 1) is the trajectory of a dust particle that can be modeled based on the terminal velocity (Vt) of the dust particle settling in still air and the velocity of the air flow in the transfer point (Vair). The result of these two velocities using the enclosure height (H) as the vertical drop distance indicates the length (L) necessary to settle the dust particle. If the terminal velocity of the particle is very small and the transfer point air speed is relatively large, the settling distance can be quite long. Using the commonly applied Stoke's Law, a 10 µm respirable limestone dust particle in an air stream traveling 1,0 m/s is predicted to take 75 m to settle by gravity alone!

Air is very compressible and will find the path of least resistance. With current designs the air is most often speeding up significantly to flow under or around a single exit dust curtain with narrow slits, resulting in re-entraining the dust particles in the exhaust. Therefore, it's necessary to create recirculation regions inside a transfer point to improve dust settling.

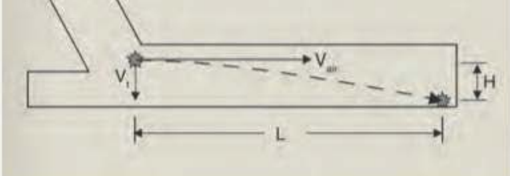

Figure 1: Dust particle trajectory

2 Methodology

A 1200 mm wide belt with 35-degree troughing idlers handling limestone was selected to establish a baseline for comparison. A belt speed of 2,0 m/s was selected as typical. Belt AnalystTM was used to calculate the volumetric flow of the bulk material, providing the cross-sectional area and the trajectory of the material onto the 1200 mm receiving belt.

Several initial analyses were performed to determine whether it was necessary to model the complete transfer from discharge to receiving conveyor (› Fig. 2) and what effect the bulk material surcharge cross section flowing through the conveyor had on results. It was found that the data being sought dust particle emissions was not significantly affected by modeling the bulk material flow. The models used for analysis reduced the chute area by 0.16 m^2 and the belt surface was represented as the flat bottom of the skirtboard extension as seen in › Figs. 3 and 4.The chute width in line with the transfer was reduced 200 mm from 800 mm so the resulting chute cross section used was 600 mm x 600 mm. Similarly, the surcharge surface of the bulk material was eliminated and the bottom of the skirtboard enclosure flattened to represent the belt surface. The FLOW software allows application of wall conditions, so the surface representing the bulk material was set to absorb any particles that contacted it inside the enclosure.

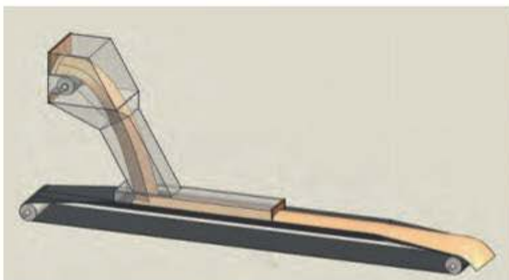

Figure 2: Experimental standard conveyor transfer point

Figure 3: Cross-sectional area per meter

PROCESSING

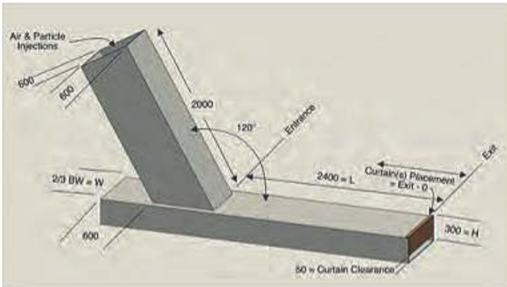

Figure 4: Standard conveyor

SolidWorks computational fluid dynamics simulation software was used to compare the relative effectiveness of different discharge chute and skirtboard extension designs based on the percent of dust particles between 1 and 100 µm in diameter that exit the skirtboards. A standard 1 200 mm wide troughed belt conveyor based on the common rules of thumb was selected as the basis for comparison, with a belt speed of 2 m/s and a generic bulk material having a solid density of 1 500 kg/m³ (❱ Table 1).

Because of the limitations of the software, a trial and error approach varying several parameters was used to explore design parameters that minimized dust emissions. Numerous combinations were used to determine the relative effects of the main design variables. Three basic chute configurations (❱ Figs. 5 a-c) were decided upon for analysis:

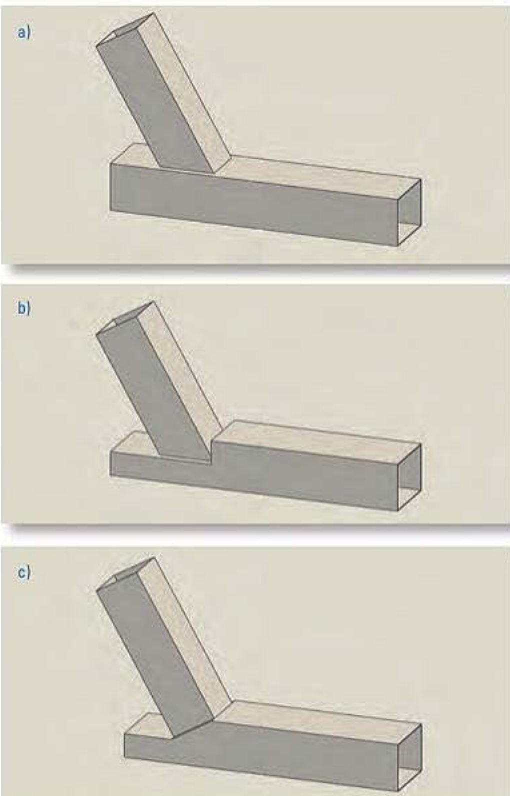

Figure 5: a) standard chute configuration; b) retrofit; c) mitered

Table 1: Primary experimental variables

Parameter	Unit	Standard conveyor	Experiment variables
Belt speed	m/s	2.0	2.0 to 8.0
Belt width	mm	1 200	600, 1 200 and 1 800
Bulk material solid density	kg/m³	1 500	750, 1 500 and 3 000
Air flow	m³/s	0.5	0.25, 0.5 and 0.75
Curtain placements		One at the exit	One to six curtains at various spacings
Curtain clearance	mm	50	0 to 150 above load
Skirtboard height	mm	300	300, 600 and 900
Skirtboard length	mm	2 400	2 400, 3 600 and 4 800
Wall roughness	mm	1	0 to 100
Chute to skirtboard		Standard inline	Mitered, full width and 90 degrees
Tail box length: 600 mm		300 high	300, 600 and 900 high
Dust particle diameter	µm	All configurations modeled with 100, 50, 40, 25, 10 and 1 µm dust particles	

Several analyses were run in the external mode, with the receiving belt and the chute spaced 1 mm from the belt to simulate seal leakage and dust dispersion around the conveyor. Altogether several hundred conveyor configurations were analyzed, representing several thousand data points.

There are many options in SolidWorks FLOW for displaying and exporting the results. ❱ Fig. 6 shows the particle trajectory results of an external analysis for a Standard Conveyor where the moving conveyor belt is included and without any cross winds. Red indicates the highest velocity which can be seen beginning where the air flows under the curtain. The air flow created by the moving belt is then at a slower speed until it reaches the discharge pulley where it again speeds up. Many other properties can be displayed, such as particle trajectories and pressure regions. External analyses also allow the addition of environmental conditions such as wind and temperature.

❱ Fig. 7 shows a typical internal analysis for a Standard Conveyor with the exit curtain inside the chute. This graphic includes both the air and dust particle paths. The air flow is depicted as solid lines, while the dust particles are small spheres. The rectangular outer enclosure is called the Computational Domain. This is the volume that is meshed into a 3D grid for mathematical analysis. In an external analysis the entire computational domain is analyzed, which requires about 1.0 h of time to obtain results. An internal analysis only considers the air flow in contact with the chute, skirtboards and curtains and takes about 15 min of CPU time. For this reason, most analyses were done as internal studies.

3 Results

The criteria used to judge the effectiveness was the average percentage of nuisance and respirable dust particles that exited the skirtboard enclosure compared to the number of particles injected into the discharge chute. The health and safety aspects of dust particles depend upon their

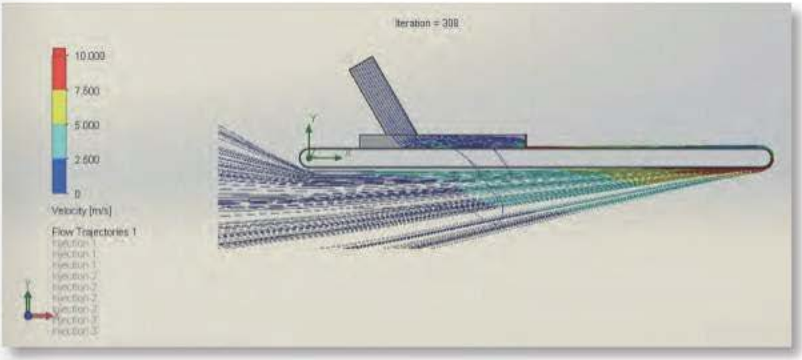

Figure 6: Typical external FLOW analysis graphic

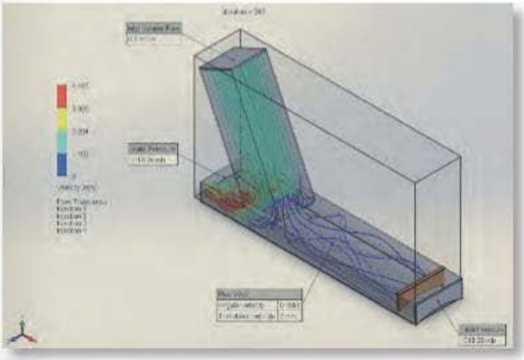

Figure 7: Typical internal FLOW analysis graphic

combustibility and toxicity properties. In this study the bulk material was a nondescript inert material only characterized by its solid density. Nuisance dust usually refers to those particles which do not cause health issues but do accumulate to present housekeeping and equipment degradation issues. Respirable dust particles are usually referred to as those particles that impair breathing or cause long-term lung diseases, disability or death. For the purposes of this study, nuisance dust particles were considered as the 100, 50, 40 and 25 µm particles. The solid density was 1 500 kg/m³ and the respirable dust particles were considered the 10 and 1 µm particles. For reference, individual dust particles of the 40 µm size and larger are generally visible to the naked eye.

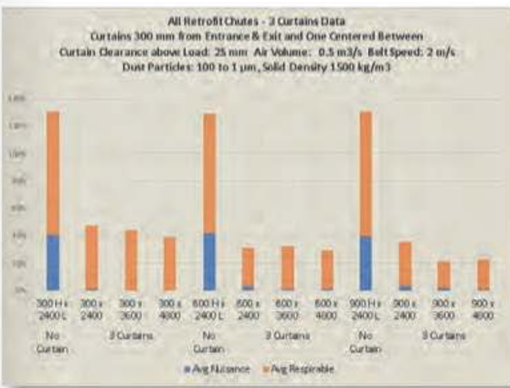

Figure 8: Summary of all 3-curtain results

❱ Fig. 8 shows the results of using three curtains vs. no curtains. Since most conveyor dust curtains in use are a single exit curtain poorly maintained, the curtains are of little value in reducing dust emissions. Therefore, the comparison is to a skirtboard extension without curtains.

3.1 Preferred embodiments

The best value for the cost of the skirtboard enclosure and its effectiveness is judged by the researcher as skirtboards 600 mm high and 3600 mm long, using either the retrofit or mitered discharge chute-to-skirtboard connection. The actual difference in performance in reducing dust emissions is small for the longer 4800 mm and taller 900 mm skirtboards compared to the cost and performance of the 600 mm high and 3600 mm long enclosures when both options have three curtains spaced 300 mm from the entrance and exit and one in the center.

The junction between the discharge chute and the skirtboards was found to be an important design detail for creating recirculation (❱ Figs. 9 a and b). Most conveyor engineers and manufacturers use 300 mm high skirtboards, because this height is about the minimum for installing a sealing system and wearliners. The retrofit and mitered junctions were significantly more effective than a simple butt connection and 300 mm height as shown in the standard conveyor in Fig. 4.

In most of the models the discharge chute was 200 mm narrower than the skirtboards. Making the width of the discharge chute narrower than the width of the skirtboard helps to fold the air flow going into the first curtain, and that encourages distribution of the air flow toward the top of the

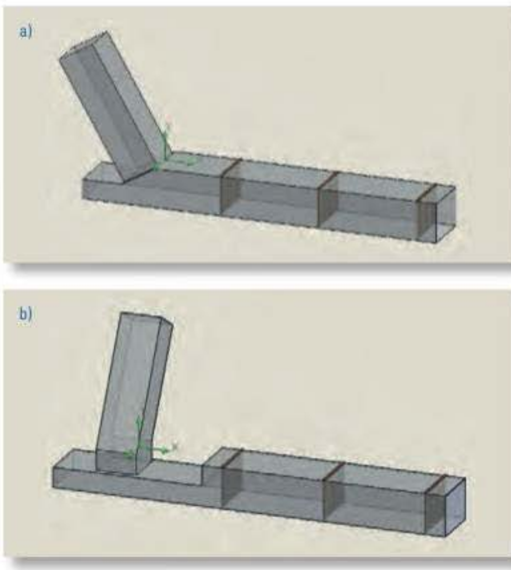

Figure 9: a) preferred inline transfer new construction; b) preferred angle or retrofit transfer

PROCESSING

enclosure rather than along the surface of the bulk material. Individual parameters and their results are discussed below.

3.2 Length of skirtboard

It was found that for most situations a 3600 mm long skirtboard produced the best results (Fig. 10). This length in combination with the optimum curtain placement and a 600 mm high enclosure seems to be the optimum combination of performance and cost of the transfer. Increasing the length to 4800 mm and height to 900 mm had some marginal effect, but is probably not worth the extra cost.

3.3 Height of skirtboard

One interesting observation for the 300 mm high standard conveyor skirtboards was that as length or air volume increased, the dust settling performance decreased (Fig. 11). It was found that the boundary layer between the air flow, the bulk material and chute walls increases in thickness and created a venturi effect, spewing more dust out of the exit. When the skirtboard height was increased to 600 mm this effect became insignificant. Additional height beyond 600 mm did reduce nuisance emissions while increasing respirable dust discharge, because the settling path is greater in the higher enclosure.

3.4 Height of tail box

The tail box had little effect on dust emissions out of the exit end of the skirtboards. In most configurations the height of the tail box was set at 300 mm. The tail box length was set at 600 mm to match the typical 600 mm idler spacing used in the load zone by most conveyor manufacturers and engineers. Very little air flow or pressure increase was observed in the tailbox for most configurations, so its main function should be considered reducing roll back of material and creating a means to effectively seal past the corner of the loading chute.

3.5 Air flow

Three different air flow volumes of 0.25, 0.50 and 0.75 m^3/s were used to represent induced air. For reference, 0.50 m^3/s is about 1000 cfm. As would be expected, the average air velocity through the skirtboards was directly proportional to the induced air flow. The maximum air velocities in the skirtboard are almost always found where the air flows under the skirtboard curtains. Air velocities of 30 m/s were common under the curtains, with up to 90 m/s observed. These high air speeds keep the respirable dust suspended, so reducing induced air into the chute is important in improving performance.

Length of the skirtboard had some effect on dust discharges for the Standard Conveyor with a single exit curtain. With three curtains spaced 25 mm above the belt there was a similar reduction in the emission ratios but at a much lower percentage of particles escaping. Keeping the air flow consistent (and therefore the flow of bulk material) through the transfer is important to improving dust settling. Different baffle arrangements were tried to encourage recirculation within the discharge chute and the skirtboards, with little effect.

3.6 Curtains

Numerous combinations of curtain widths, angles and clearances above the bulk material load were examined. Curtains made of porous materials and curtains with large holes were investigated. The conventional slit curtain is the most practical curtain design and produced the most acceptable results. For most studies the curtains were the full width of the skirtboard. The curtains strips were nominally 50 mm wide and spaced at different clearances above the bulk material. It was found that a gap between the strips of at least 5 mm was necessary to cause air flow through the curtain rather than under it. Some work was done with wider gaps, and while more investigation is warranted, it appears that a gap of 10 to 15 mm produces the best combination of recirculation and keeping the average air speed inside the skirtboards more uniform and at a lower velocity.

As the distance the bottom of the curtain was spaced above the bulk material increased in increments of 25 mm, the dust control performance decreased. At 100 mm above the load the results were close to not having a curtain at all. The Industrial Ventilation Handbook recommends 50 mm. Best dust control performance was with the curtain touching the bulk material flow but this is impractical due to wear and load variations, so comparisons were done with the curtain spaced 25 mm above the belt.

Many combinations of curtain locations and numbers were tried. Regardless of curtain clearance (Fig. 12) above the conveyed material, the best location for a full width slit single exit curtain was between 300 and 450 mm from the exit of the skirtboards. When multiple curtains were tried, the best combination was with a curtain 300 to 450 mm from the beginning of the skirtboards, one curtain in the center and the exit curtain 300 to 450 mm from the exit. This pattern

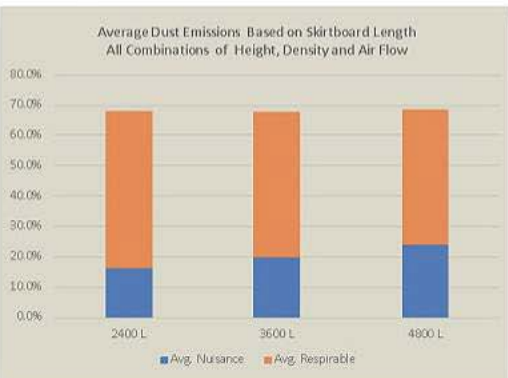

Figure 10: Average dust emissions by skirtboard length

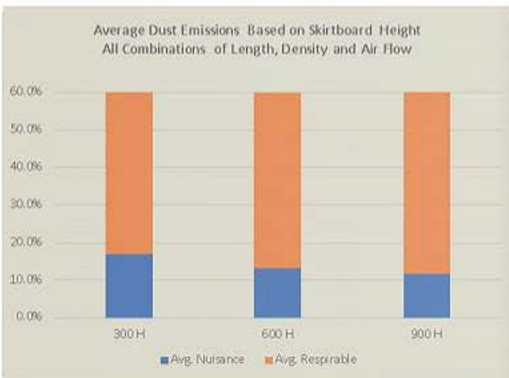

Figure 11: Average dust emissions by skirtboard height

PROCESSING

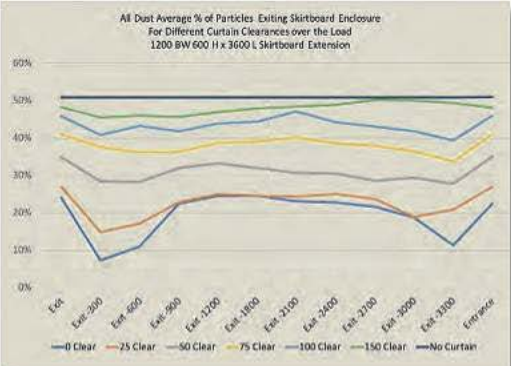

Figure 12: Curtain clearance above load vs dust emissions

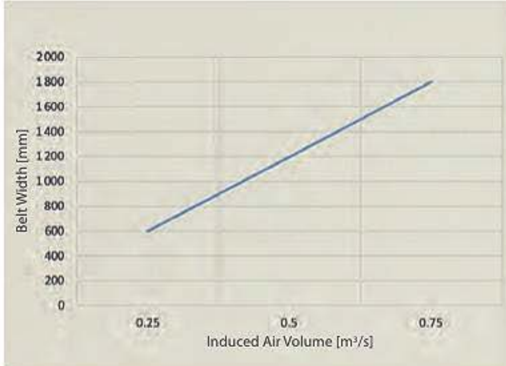

Figure 13: Recommended maximum induced air volumes

was found for all skirtboard lengths, heights and belt widths. A minimum of two chambers created by the spaces between curtains was necessary to create recirculation patterns within the skirtboards. Recirculation within the chambers created longer settling paths for the respirable dust, which improved dust control performance. Slight improvement was found by increasing the number of curtains and evenly spacing them. Configurations up to six curtains were tried. Staggered curtains and combinations of full width and staggered curtains did not improve performance.

4 Return On Investment/Net Present Value

There is only a little available content in the literature about dust levels at the transfer between the discharge and the skirtboard. A few references were found indicating a few kilograms per hour of airborne dust. While nuisance dust can be a problem, there is insufficient quantity in most cases to justify an ROI on reducing cleanup labor.

A stronger case can be made for respirable dust reducing capabilities of the preferred designs, particularly for silica dust. The current standard for silica dust is 50 mg/m^3 per hour over an 8 h exposure. The calculation for exposure involves sampling the total dust load averaged over 8 h. The percentage of silica in the sample is determined and this number times the average dust loading determines the exposure. If designing or rebuilding a transfer can reduce the overall respirable dust load, it can therefore reduce the exposure to silica. In some cases, respirator use or active dust collection can be eliminated. Foundations for Conveyor Safety discusses in detail how to use reduction of respiratory disease, life cycle analysis for equipment and improvements in productivity to justify additional upfront engineering, improved components and better enclosure design.

5 Field verification

Since the software does not allow modeling the flow of the bulk solids, field verification of the simulation results would be beneficial. It is envisioned that an existing conveyor be found where initial dust measurements can be taken over a period of time. Then the transfer point rebuilt to the recommended 600 mm high by 3600 mm long with accommodation for installing multiple curtains that can have their positions varied. Once the retrofit is completed, additional dust measurements would be taken over time for comparison to the results from the SolidWorks FLOW Simulation software.

A second project is of interest in the optimization of skirtboard enclosures. No engineering basis was found for the rules of thumb on skirtboard length. Presumably these accepted parameters deal with the distance necessary for the load to settle down in the skirtboards. A scale model study could be designed to test different configurations of chutes and shapes of bulk materials to verify the assumptions or develop new ones with an engineering basis.

6 Further considerations

6.1 Effect of the bulk solids

One significant variable that cannot be included effectively in SolidWorks FLOW is the modeling of the bulk material flow turbulence as it flows through the discharge chute and impacts the receiving belt. The software limits particle mass to less than 30 % of the air mass in the volume to be analyzed. There is about 0.6 kg of air in the standard conveyor enclosure, so the particles that can be introduced need to have a total mass of less than 0.18 kg.

6.2 Material loading turbulence settling

There are two commonly-accepted guidelines for the length of the skirtboards: 1.2 m of skirtboard length for every 1,0 m/s of belt speed or two times the belt width. For the standard conveyor in this study, these rules both suggest a skirtboard extension of 2.4 m. No source could be found for these assumptions or any alternative suggestions based on engineering principles, but it is presumed that they are based on the distance required for the load to settle down into a consistent profile after loading.

6.3 Induced air

Most conveyor engineers and handbooks promote the induced air formula proposed by Anderson in 1964 for estimating air induction into a transfer point. This is the same equation that Martin Engineering has recommended in its foundations reference book:

$$Q_E = 10 \cdot A_U \sqrt[3]{\frac{RS^2}{D}} \qquad (1)$$

with:

Q_E: Exhaust volume in cubic feet per minute
A_U: Enclosure upstream open area in square feet
R: Rate of material flow in tons per hour
S: Height of material fall in feet
D: Average material size in feet

PROCESSING

Most articles on settling chambers recommend the average air velocity for gravity settling of dust be 1.5 m/s or less. Engineers typically suggest 1.0 m/s for skirtboard enclosures. The results of FLOW analysis indicate that average velocity can be ≥ 1.5 m/s and still have effective dust settlement, if recirculation can be made to happen in the skirtboard extension. For the conveyor widths studied, induced air volumes should be limited to those in ❯ Fig. 13.

As equalition (1) indicates, for a given bulk material size (D) and tonnage (R), the designer has two variables to control induced air. The drop height (S) is often minimized (to the detriment of access for belt cleaner installation and pulley maintenance) to keep the overall height of the conveyor transfer within building or structure confines, reduce degradation and keep costs down. That leaves the designer with the task of reducing the open area (Au). The largest and most difficult open areas to seal are where the discharging conveyor enters and leaves the head chute. Traditionally a single dust curtain is installed on the load side of the belt as the cargo enters the head chute and where the belt exits the dribble chute. There may or may not be a seal between the upper and lower runs of the belt. These curtains and seals are also typically poorly maintained, which directly adds to the open area and the amount of induced air.

7 Final remarks

The results clearly indicate that unless the dust curtains are properly spaced and kept adjusted close to the bulk material profile, the performance in passive reduction of dust emissions is significantly reduced.

Controlling the amount of air flow through the transfer is also critical. Extending the head chute back to the first full troughing idler on the carrying side and using two curtains plus sealing the area between the top and bottom runs is critical in reducing induced air flow. And above all, the dust curtain systems must be accessible and maintainable to gain the benefits of passive dust suppression. ◂