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Dust Suppression Hopper:

reduces dust liberation during bulk loading: Two case studies

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Abstract

After industrial sand has been mined and processed, the finished product is typically loaded into small bags of 45 kg (100 lb) or less, large bulk bags of 454 to 1,361 kg (1,000 to 3,000 lb), or vehicles such as trucks or trains for transport to end users. As the sand is being transferred and loaded, dust can be released into the work environment, potentially exposing workers to respirable crystalline silica. A number of control technologies have been developed and utilized in an effort to reduce dust liberation during loading operations. For bulk loading into trucks or trains, the U.S. National Institute for Occupational Safety and Health (NIOSH) evaluated one of these technologies, the Dust Suppression Hopper (DSH), at two industrial sand processing plants. Results from these case studies show that the DSH reduced airborne respirable dust levels by 39 to 88 percent, depending upon the product size being loaded.

Introduction

Inhalation of respirable crystalline silica dust can lead to the development of silicosis, a disabling and potentially fatal lung disease. Once contracted, there is no cure for silicosis, so the goal is to prevent the development of the disease by limiting exposure to respirable dust containing crystalline silica at or below the exposure limit of 50 μg/m^3 recommended by the U.S. National Institute for Occupational Safety and Health (NIOSH, 2002). At industrial silica sand operations, the product contains high levels of crystalline silica, so effective control technologies are needed to minimize the respirable dust exposure of workers.

NIOSH, in partnership with the Industrial Minerals Association–North America, published a dust control handbook (NIOSH, 2012) focused upon control technologies for industrial-mineral mining and processing operations. One chapter in this handbook discussed technologies for controlling dust liberated during bulk loading, including telescoping loading spouts, dust collection systems for loading spouts, enclosures for load-out areas and a newer technology known as Dust Suppression Hopper (DSH).

As a product stream falls through the air during bulk loading, particle separation, air entrainment and increased particle velocity occur. When the product deposits in the targeted

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container, the product stream compresses and liberates dust-laden air (Sutter, Johnston and Mishima, 1982). As falling height increases, dust liberation increases (Cheng, 1973; Cooper and Arnold, 1995). Telescoping loading spouts have been in use for years and can be effective in controlling dust, particularly when equipped with an integrated dust collection system. These spouts can be lowered to the receiving vessel and shrouded to minimize exposure to ambient wind. Cascading-type spouts minimize the free-falling distance and velocity of the product by preventing direct fall through the spout (NIOSH, 2012). However, the cost and complexity of adding dust collection systems and maintenance of the spouts can be a concern, particularly when dealing with abrasive products such as silica sand.

DSH is a technology developed in New Zealand (Wypych, 2009) with the goal of providing a simpler means of reducing dust liberation during bulk loading into trucks, trains or ships. As shown in Fig. 1, the DSH is a cone-shaped unit designed to force the product into a solid stream prior to discharge into the vessel to be loaded. The DSH is equipped with a stationary central plug that is surrounded by a conical hopper. The hopper is suspended from the top frame by multiple springs. These springs hold the hopper closed against the plug until sufficient mass has accumulated to extend the springs and lower the conical hopper (DSH Systems, 2017). According to the design principle, this mode of operation provides two benefits from a dust control perspective. As the product loads into the hopper, mass continues to build until it has sufficient force to overcome the springs. The pressure created by this building mass causes the air trapped within the loaded product to be forced out, which minimizes dust liberation from the product when it lands in the loading vessel. Also, when the product is ultimately released from the hopper, it flows as a condensed column (Fig. 1c) rather than an unconsolidated stream, minimizing air entrainment and dust escape.

When DSH information was included in the dust control handbook, there were no known industrial sand installations in the United States that had been evaluated for dust control effectiveness. In the last few years, two industrial sand producers decided to install DSH units at their operations and presented NIOSH with an opportunity to evaluate their performance. One goal of the NIOSH mining research program is to identify control technologies that can be implemented by mine operators to reduce crystalline silica dust exposures. Therefore, NIOSH conducted dust control evaluations at these processing plants.

Test sites

At plant A, several storage silos, each equipped with rigid loading spouts, were used to load industrial sand into over-the-road trucks for transport off-site to customers. Fines, as a byproduct of the various processing operations, were stored in another silo and loaded through a rigid spout into a mine-owned truck (Fig. 2a) for transport back to the mine. The DSH was installed at the fines load-out location. A bucket lift system was also installed so that the various silos could discharge to this bucket lift, which would then carry the various products up to the DSH (Fig. 2b).

At plant B, an enclosed conveyor transported industrial sand from the processing plant to the load-out location, where over-the-road trucks were loaded for transport to customers. In addition, a mine-site articulating truck was periodically used to haul product for dumping on mine property. The load-out operator would select the size of product to be loaded into each truck, and all products were then conveyed and loaded at the same location. A telescoping spout was available at the load-out (Fig. 3a) but was not being raised and lowered during the baseline sampling because of maintenance issues. The telescoping spout was replaced with a DSH (Fig. 3b), but no other changes to the loading facility were made. Six different product sizes were loaded during NIOSH sampling at plant B.

The DSH is available in various sizes with different loading capacities. At both plants, the DSH 1 model was installed. This model is rated at 181 to 281 t/h (200 to 310 stph) for a product with bulk density of 1,602 kg/m^3 (100 lb/ft^3).

Sampling protocol

Gravimetric and instantaneous dust sampling instruments were used to monitor levels of airborne respirable dust, with particle size smaller than 10 µm. The gravimetric samples were collected with Zefon Escort ELF personal sampling pumps (Zefon International, Ocala, FL) operated at 1.7 Lpm and connected to a Dorr-Oliver 10-mm nylon cyclone fitted with a polyvinyl chloride filter with diameter of 37 mm. The filters were pre- and post-weighed in the environmentally controlled weighing facility at the NIOSH Pittsburgh laboratory. Real-time dust sampling was conducted with the Thermo Scientific personal DataRAM pDR-1000AN monitor (pDR) (Thermo Fisher Scientific, Waltham, MA), which uses light-scattering technology that has been optimized to measure respirable dust. The pDR instruments were set to record a reading every two seconds for these surveys. Because the response of light-scattering instruments can be affected by the physical properties of the dust being measured, the relative dust readings from the pDR were adjusted with a ratio determined from the adjacent gravimetric samplers (Thermo Scientific, 2007). For each day of sampling, a unique gravimetric-to-pDR ratio was calculated for each sampling location, with all individual pDR readings at that location multiplied by this ratio.

As each truck was being loaded, area dust sampling was conducted at the bed of the truck and did not measure worker exposure. At each sampling location, three gravimetric samplers and one pDR sampler were positioned adjacent to one another on a sampling rack (Fig. 4a). At plant A, sampling only occurred with the mine-operated truck and on an intermittent basis. As a result, NIOSH researchers were able to hang sampling racks on this truck prior to the start of loading and remove the racks from the truck after it was loaded. This process was repeated when the emptied truck returned from the mine. Four sampling racks were used, with one rack placed in each corner of the truck bed. Each rack was positioned a few centimeters below the side rails within the interior of the truck bed (Fig. 4b). Because the sampling racks were within the confines of the truck bed, high dust levels could be anticipated. Therefore, NIOSH rezeroed the pDR samplers multiple times during the sampling day to ensure the samplers continued to operate properly.

At plant B, the majority of the trucks being loaded were over-the-road trucks on a production schedule. As a result, NIOSH could not place sampling racks directly on these trucks. Portable sampling stands were fabricated that could be adjusted for vehicle height. After the trucks pulled into the loading position, NIOSH researchers would move the sampling stands into position and adjust the stands so that the sampling racks were suspended several centimeters above the sides of the truck bed. Once again, four sampling racks were used, with two on each side of the truck centered around the loading point. Figure 5 shows the sampling stands positioned around the mine truck. After each truck was loaded, NIOSH researchers moved the sampling stands out of the way so that the next truck could pull in to be loaded.

For each truck, NIOSH researchers recorded the beginning and end times for loading. These times were then used with the adjusted pDR real-time data to calculate a dust concentration for the loading period at each sampling location. The dust concentrations from the four sampling locations were then used to calculate an average concentration for each truck that was loaded. Averaging of dust data from the four sampling locations around the loading point minimized the impact that wind direction could have on sampling results.

Data analysis

The goal of the data analysis was to directly compare dust levels liberated during loading with existing equipment at each plant to dust levels liberated with the DSH installed. However, at plant A, modifications to the load-out facility — bucket lift and DSH — resulted in a substantial increase in loading time, so the dust data were normalized for loading time. At plant B, a variety of product sizes were loaded but not all sizes were loaded during both sampling periods, so direct comparisons could not be made for all products.

As noted previously for plant A, the mine truck was loaded with fines during all sampling periods. For baseline sampling with the fixed loading spout, 11 trucks were sampled. After the DSH was installed, NIOSH sampled 11 trucks during one visit (DSH1) and returned to the plant six weeks later to sample another 11 trucks (DSH2). The two sampling periods with the DSH provided an indication of the variability that may be present during loading.

At plant A, the installation of the bucket lift and DSH altered the truck loading times when comparing baseline sampling data to DSH sampling data. The average loading time per truck was 6.8 min for the baseline sampling, 13.5 min for DSH1 and 13.8 min for DSH2. Average baseline dust concentrations for individual trucks (dependent variable) were plotted against the corresponding loading times (independent variable). Regression analysis indicate that a power equation — $y = 348.11x^{-0.612}$ $R^2 = 0.5713$ — provides the best fit to the data and that changes in loading times account for approximately 57 percent of the change in dust levels. Prior research (Heitbrink, Baron and Willeke, 1992) showed similar trends. As a result, all dust levels were normalized by multiplying the average dust concentration for each truck by a factor determined by dividing the individual loading time for that truck by the average loading time observed during the baseline sampling.

Figure 6 illustrates the normalized dust levels for all 33 trucks sampled at plant A, with 11 trucks sampled during each of three different sampling periods: baseline, DSH1 and DSH2. Table 1 summarizes the mean dust concentrations and standard deviations calculated for each of these sampling periods. The 95 percent upper (UCL) and lower confidence limits

(LCL) are also provided in Table 1 for each sampling period. These statistics were calculated using the Descriptive Statistics data analysis tool in Excel.

The 95 percent confidence intervals for the average loading times (not shown) and dust concentrations from each DSH sampling period overlap, indicating that the DSH performance between sampling periods was not statistically different. Consequently, data from the two DSH sampling periods were combined and resulted in an average concentration of 12.6 mg/m^3 for these 22 trucks. When compared to the average baseline dust level, the DSH reduced average dust levels by 88 percent, which was statistically significant at a 95 percent confidence level.

At plant B, 32 trucks were sampled under baseline conditions with the loading spout. Four different product sizes were loaded during the course of the survey and included 20/40, 40/70, a blend and fines. The numbers in the size designation refer to the mesh size that was used to screen the product, with the first number representing the top size cut and the second number representing the bottom size cut. For example, 20/40 represents particles that passed through a 20-mesh screen but did not pass through a 40-mesh screen. Representative samples were collected and analyzed at the plant to ensure the desired product size was being achieved. The blended product during baseline sampling consisted of 60 percent 30/50 product and 40 percent 20/40 product.

With the DSH operating at plant B, 42 trucks were sampled. Five different product sizes were loaded in the course of this survey, including 20/40, 30/50, 40/70, a blend and fines. During this sampling period, the blended product contained 50 percent 30/50 and 50 percent 40/70, so a direct comparison to the blend from the baseline survey could not be made.

The truck loading times observed for equally sized products loaded during both sampling periods at plant B were much closer to one another than at plant A. The average loading time with the spout was 8.5 min for 20/40 and 10.0 min for the fines, with the average DSH loading times within 5 s of these spout averages. The average difference in loading time for the 40/70 sized product was 54 s (8.9 min versus 9.8 min). As a result, no normalization of dust levels was completed for the plant B data.

Table 2 summarizes the mean dust concentrations and standard deviations measured for each product size during the baseline and DSH sampling periods at plant B. The 95 percent confidence intervals are also provided for products with three or more trucks sampled.

Figure 7 illustrates the average dust concentrations for each product size loaded during the baseline and DSH sampling periods. As anticipated, loading of the fines produced the highest dust levels for both sampling periods. The DSH reduced average dust levels produced by loading fines by a statistically significant 84 percent. A statistically significant reduction of over 39 percent was also observed for the 40/70 product. With only two data points for the 20/40 product obtained during the baseline sampling, a 95 percent confidence interval was not calculated, but the DSH reduced dust levels by nearly 85 percent for this product.

As noted previously, the composition of the blended product being loaded with the DSH was different from that loaded during baseline sampling. However, 30/50 and 20/40 products were individually loaded with the DSH and liberated similar dust levels: 1.15 versus 1.36 mg/m^3. Although not truly representative of an actual blended product, the average concentrations for the 30/50 and 20/40 were combined to estimate a weighted-average, “calculated blend” concentration — $0.6 \times 1.15 + 0.4 \times 1.36 = 1.23$ mg/m^3 — to provide another opportunity for a comparison to baseline dust levels. The DSH levels for this calculated blend were nearly 70 percent lower than the levels for the blended product sampled during the baseline survey.

One issue observed with the DSH at both plants occurred when the loading of each truck was completed and product flow to the DSH was ending. Prior to the conical hopper being pulled back up to fully seal against the stationary plug, silica sand would continue to be discharged, creating a trailing plume as shown in Fig. 8. This unconsolidated discharge would last from 30 s to more than one minute, with the potential to expose workers downwind of this plume. This dust liberation was not included in the dust concentrations calculated during the loading of each truck.

Summary

NIOSH conducted respirable dust surveys at two silica sand processing plants to quantify dust levels generated during the bulk loading of sand into trucks. The objective of this research was to compare respirable dust levels liberated with the original load-out method used at each plant to the levels when a DSH was used. The DSH is a relatively new method of bulk loading that has been adopted over the last several years by some silica sand producers in the United States. Area sampling was conducted to quantify dust liberation before and after the DSH was installed at each plant.

At plant A, baseline sampling was conducted while a rigid loading spout was being used to load fines generated during processing operations into a mine-operated truck. Sampling packages were hung at each corner of the truck bed to monitor respirable dust liberated as the fines were loaded into the truck. The dust concentrations from these four sampling locations were used to calculate an average truck concentration, which mitigated the impact of wind direction. Sampling results indicate that loading with the DSH reduced truck dust levels by 88 percent when compared to baseline levels, which was statistically significant at a 95 percent confidence level.

At plant B, six different product sizes were loaded into over-the-road trucks or a mine-operated truck throughout the course of NIOSH sampling. All product sizes were loaded at the same load-out location, but not all of the product sizes were loaded during both baseline and DSH sampling periods.

Using portable stands, four dust sampling packages were positioned around the truck loading point to monitor respirable dust liberation, similar to plant A. For baseline and DSH testing, the highest dust levels were observed while fines were being loaded. The DSH reduced fines-generated dust levels by 84 percent, which was statistically significant at a 95-

percent confidence level. Two other product sizes were loaded during both baseline and DSH sampling periods. Dust levels when using the DSH were reduced by more than 39 percent for 40/70 product and by 85 percent for 20/40 product.

At these two processing plants, the DSH was successful in reducing airborne respirable dust levels during truck loading. The relative effectiveness in dust reduction varied based upon the size of the silica sand product being loaded. Plant operators can consider using this technology as another option for reducing dust liberation during bulk loading. Personnel working in the loading area should be aware that as the product flow to the hopper is ending and the hopper has not completely resealed, an unconsolidated dust plume continues to discharge from the DSH, with the potential for exposing them to respirable dust.

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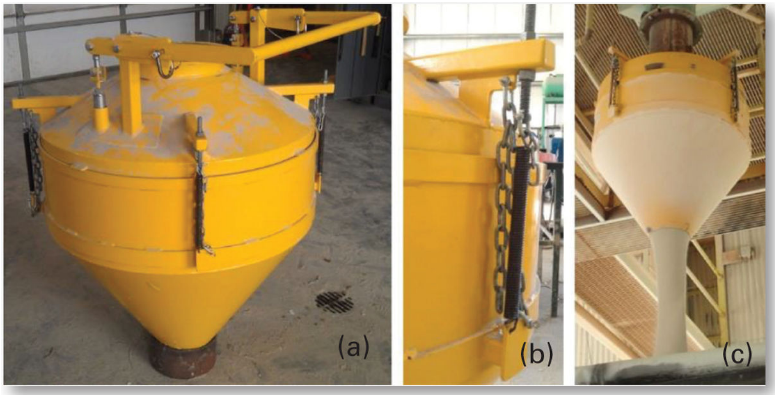

Figure 1.
(a) DSH unit in shop prior to installation, (b) DSH spring suspension and (c) DSH unit discharging sand.

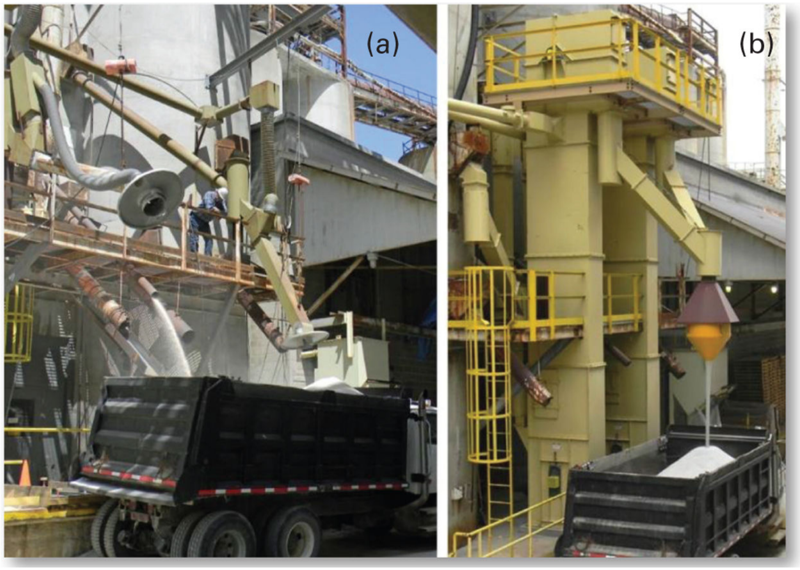

Figure 2.

(a) Rigid loading spouts from multiple silos at plant A, and (b) bucket lift and DSH installed.

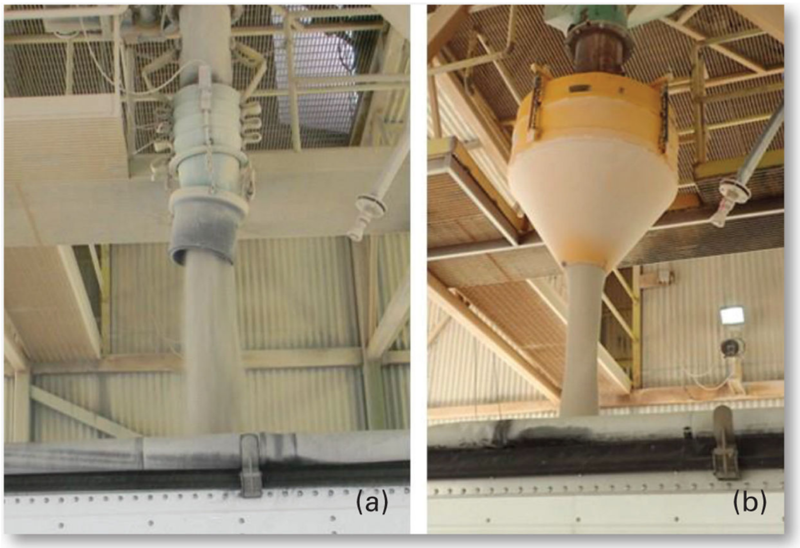

Figure 3.

Trucks being loaded at plant B with (a) original spout and (b) DSH.

Figure 4.

(a) Gravimetric and pDR sampling rack, and (b) sampling locations on truck at plant A.

Figure 5.
Adjustable sampling stands and sampling racks positioned around mine truck at plant B.

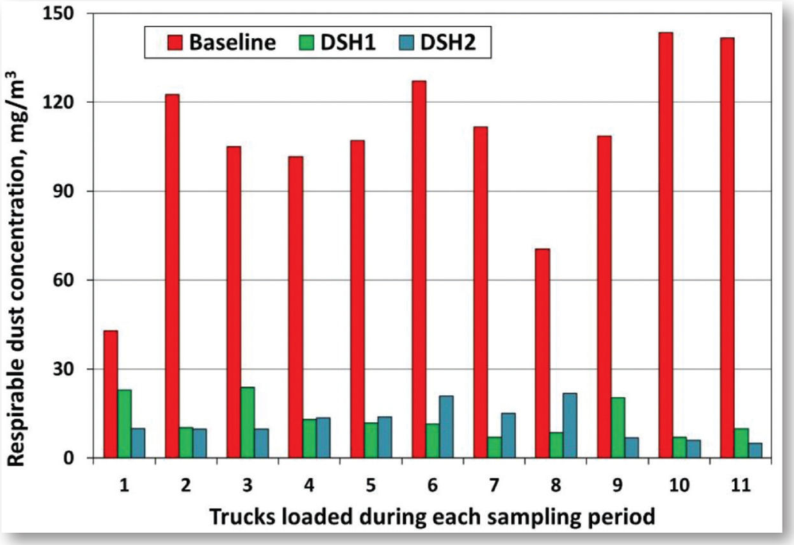

Figure 6.

Normalized dust levels for each truck sampled at plant A.

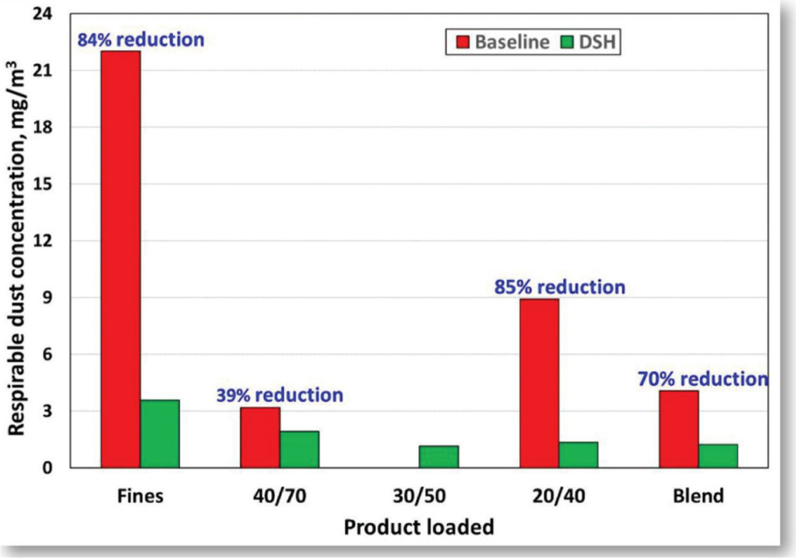

Figure 7.

Average dust levels for each product loaded during baseline and DSH sampling at plant B.

Figure 8.

Silica sand discharging from DSH as loading ends.

Table 1

Average respirable dust concentrations at plant A.

	Normalized dust concentrations (mg/m^3)			
	Baseline	**DSH1**	**DSH2**	**DSH combined**
Mean	107.4	13.2	12.0	12.6[a]
Standard deviation	29.4	6.1	5.6	5.8
Number of trucks	11	11	11	22
95% UCL	127.1	17.3	15.7	15.1
95% LCL	87.6	9.1	8.2	10.0

[a] Statistically significant difference from baseline at 95 percent confidence level.

Table 2

Average respirable dust concentrations for each product loaded at plant B (NA = not applicable).

	Baseline concentrations (mg/m^3)				**DSH concentrations (mg/m^3)**				
Product	20/40	40/70	Blend	Fines	20/40	30/50	40/70	Blend	Fines
Mean	8.92	3.19	4.07	22.03	1.36	1.15	1.93[a]	1.18	3.59[a]
Standard deviation	2.36	1.22	1.84	8.33	0.41	0.29	0.41	0.05	0.30
Number of trucks	2	12	12	6	7	13	17	2	3
95% UCL	NA	3.97	5.24	30.77	1.74	1.32	2.14	NA	4.32
95% LCL	NA	2.41	2.90	13.29	0.98	0.98	1.72	NA	2.86

[a] Statistically significant difference from baseline at 95 percent confidence level.