Methods to Lower the Dust Exposure of Bag Machine Operators and Bag Stackers

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This article reviews various dust control technologies developed over the years at the Pittsburgh Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) to provide various options and alternatives to lower bag machine operators' and bag stackers' dust exposures. Dust exposure records for the past 20 years show that bag machine operators and bag stackers normally have the highest respirable dust exposures of workers at mineral processing plants. A substantial amount of research has been performed over the years to minimize the dust exposure to these workers and the intent is to present all this information together in one article. Most of the research describes engineering controls that were adapted to existing facilities to reduce the dust generated during bag filling, bag conveying, and bag stacking. In some cases, a single technique succeeded in lowering respirable dust concentrations for all three processes, thus reducing the dust exposure to both the bag machine operator and the bag stacker. In other cases, a technique was developed to specifically reduce the dust exposure of one process or the other. This research also reviews various controls for secondary dust exposure, including general ventilation requirements to mill buildings, the effects of background dust sources, and personal work practices. This information is presented to help industrial hygienists, plant managers, engineers, and workers lower the dust exposure of bag machine operators and bag stackers.

Keywords Respirable Dust, Dust Control, Dust Exposure, Bag Operator, Bag Stacker, Mineral Processing

The health hazards from respirable dust exposure to workers in the metal/nonmetal mining industry have been known for many years. This fact is especially relevant because there is a high prevalence of silica in the material mined at both underground and surface operations.$^{(1-7)}$ A recent ranking of excessive dust exposures throughout the metal/nonmetal mining industry places the bag machine operator and bag stacker jobs at the top of the list.

A 1995 report *Quartz Exposure Trends in Metal/Nonmetal Mining*, by Watts and Parker, addresses the silica exposure of many job classifications.$^{(8)}$ This article statistically analyzed dust compliance sampling data relative to the Mine Safety and Health Administration's (MSHA's) regulations. The authors stated "In general, mill workers and underground metal and stone miners are at the greatest risk of overexposure." They also argued that, "Milling occupations at the greatest risk include bagging and other methods of packaging or loading, and laborer and bullgang workers." As Figure 1 demonstrates, from 1975–1993, the bagger and packer occupations, referred to as the bag machine operator and bag stacker in this article, have the highest mean concentration and highest exposure to dust.

At mineral processing facilities, the material processed is usually mined from surface quarries, but it can also be extracted from underground. This ore material goes through many different stages of crushing, cleaning, and then sizing. The finished product is sold in different size ranges and volumes. It can be sold in bulk quantities where it is loaded into top-loading railcars or trailer trucks, in 2000-pound (1-ton) bags, or in much smaller bag sizes, usually in the 50- to 100-pound range. Typically, the bags are stacked on pallets at a stationary location and either taken by forklift to a warehouse or loaded directly into the shipping vehicle. In some cases, the bags are loaded directly into the transportation vehicles via a conveyor belt or snake conveyors.

The bag machine operator and bag stacker are involved with the process of bag filling and stacking the bags on pallets, respectively. The individual who fills these 50- to 100-pound bags with product is called the "bag machine operator." The bag machine operator typically works at a two- or four-station filling machine, allowing for either two or four bags to be filled simultaneously with product. Each station contains a fill nozzle from which the bag machine operator suspends an empty bag, then pushes the start button. Normally, there is one bag machine operator for each filling machine. Typically, the bag machine

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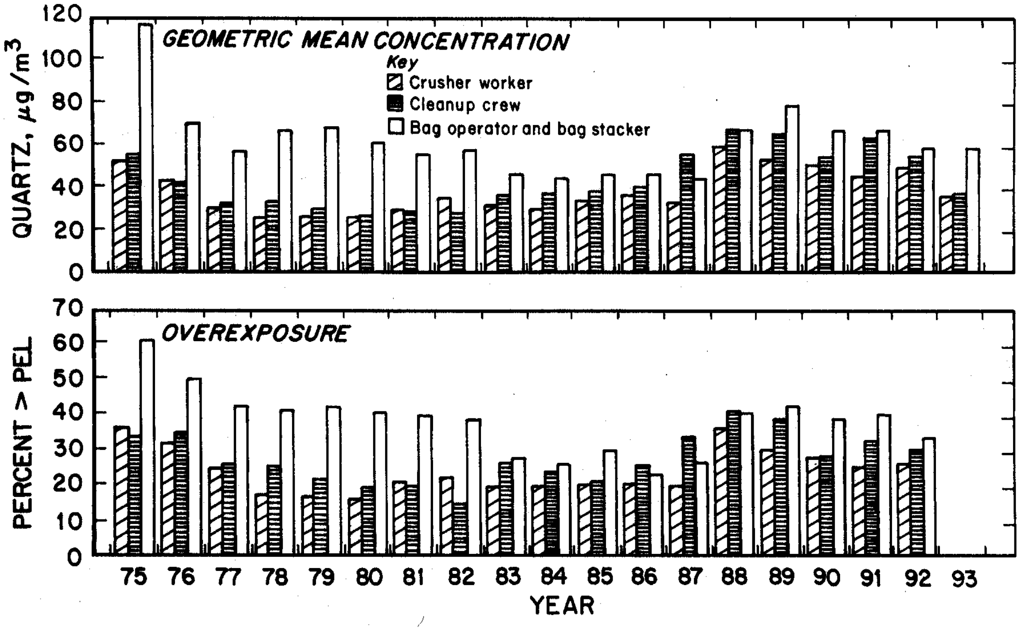

FIGURE 1
Comparison of highest worker job classifications for silica exposure in metal/nonmetal operations for 1975–1993.

operator sits on a chair that slides back and forth, allowing the operator to easily load bags from multiple spouts. When using one- and two-spout fill machines, the bag machine operator will fill the bags from the standing position. This usually occurs when the operator is also required to remove the bags manually. As each bag is filled, either an automated process in the filling machine mechanically ejects the bag onto a conveyor belt or the bag machine operator manually removes the bag and places it onto a conveyor. The bag machine operator is exposed to multiple dust sources during the various processes.(9,10) In a rare case, the bag machine operator may also be responsible for loading the bags on a pallet for shipping. If performing this duty, then the operator is also performing the "bag stacker's" job.

The work of loading full bags of product on a pallet or directly into a transportation vehicle is performed at each loading location by one or two workers called "bag stackers." This work is always performed in the standing position. In some facilities, a belt or snake conveyor carries the bags directly to a railcar or trailer truck to be loaded. In other operations, bags are loaded on pallets then taken by forklift to a warehouse or directly to a railcar or semi-trailer truck. Sometimes, the bag stacker works at a palletizer machine, which assists the stacker mechanically. Two primary dust sources to the bag stackers are product and dust on the outside of the bags and product emitted from the bag valve. The palletizing process is highly labor-intensive and lost-time injuries due to back fatigue and strains are common.

METHODS

This article will describe the following control technology developed by NIOSH at the Pittsburgh Research Laboratory to lower the dust exposure of the bag machine operators and bag stackers:

- Direct Methods for Controlling Dust Exposure
  —Dual-Bag Nozzle System
  —Overhead Air Supply Island System
  —Pallet Loading System
  —Bag and Belt Cleaner Device
  —Bag Valve Comparison
- Indirect Methods for Controlling Secondary Dust Sources
  —Total Mill Ventilation System
  —Background Dust Sources
  —Personal Work Practices

Although each of these research efforts was an individual study with many variations and differences, they all were very similar in the analysis technique and equipment used to measure respirable dust concentrations in and around the bag loading and stacking process and personal dust exposures to workers. The goal with each effort was to develop control technology that was capable of reducing the bag machine operator or the bag stacker's respirable dust exposure in a cost-effective manner.

For all efforts, respirable dust levels were initially measured under normal operating conditions. The various controls or modifications were implemented and the identical analysis procedures were repeated to determine the changes in respirable dust levels and the reduction in the workers' personal exposure levels.

Respirable dust sampling was performed in these studies using both real-time aerosol dust monitors (RAM-1) and gravimetric samplers.* Both of these sampling instruments were used with the 10-mm Dorr–Oliver cyclone to classify the respirable portion of dust, usually considered to have aerodynamic diameters of 10 microns or less.

The RAM-1 sampler is an instantaneous device that measures respirable dust concentrations by the light scatter of particles drawn through an internal sensing chamber by an air pump. This instrument has been used for many years in dust research and has proven to be a very reliable and accurate device.(11) On many occasions, the bag machine operator or bag stacker would wear a vest with the 10-mm cyclone attached to it. Flexible tygon tubing would be used to connect the cyclone to the RAM-1 dust monitor, allowing the worker the flexibility to perform his or her job function while attached to this instantaneous dust monitor.

Gravimetric dust sampling was also used for most studies. Respirable dust concentration measurements taken by each gravimetric sampling package were composed of three or four different gravimetric sampling units in a sampling rack. These sampling racks were positioned in and around the bag loading and/or bag stacking area. Each gravimetric sampler was operated at 1.7 liters/min flow as established by the MSHA for dust sampling in the metal/nonmetal mining industry in the United States.(12) The respirable dust captured by the 10-mm cyclone was deposited on a 37-mm MSA dust filter cassette. The filters were pre- and post-weighed to the nearest 0.001 mg on a microbalance. Each gravimetric sampling unit was calculated based on its own run time and then the three or four units in each sampling rack were averaged together to determine the average respirable dust concentration for the entire package.

For approximately every 10 gravimetric filters used during field testing, a blank cassette was set aside for calibration purposes. These blank cassettes remained unused but were pre- and post-weighed to determine if any biases existed in the weighing of the filters. A correction factor was determined based on the average differences between all the pre- and post-weighed blank filters. This value could be either a positive or negative value but should remain a very small value if everything was working properly. This correction factor was then applied to the final value for all field gravimetric measurements.

Again, the goal with each study was to have a positive effect of lowering the respirable dust exposure of the bag machine operator or the bag stacker while performing these two job functions.

Direct Methods for Controlling Dust Exposure

Dual-Bag Nozzle System

The dual-bag nozzle system is designed to reduce the major dust sources of the bag filling process, and thus, the bag operator's dust exposure. A number of dust sources must be controlled to achieve this goal. The primary dust sources from the fill nozzle and bag valve area are product blowback and product spewing from both fill areas. Product blowback occurs as excess pressure builds inside the bag during bag filling, then is relieved by air and product exiting the bag around the fill nozzle, creating a considerable amount of dust. As the bag is ejected from the filling machine, a "rooster tail" of product is thrown from the bag valve and fill nozzle. The rooster tail occurs because the bag is pressurized as it leaves the machine, causing product to spew from the bag and fill nozzle briefly after the bag is ejected. These dust sources release dust into the air and contaminate the outside of the bag. These contaminated bags then become a major dust source for the bag stacker, or for any other individual handling the bags.

Figure 2 depicts the components of a dual-bag nozzle system. The dual-bag nozzle device uses a two-nozzle arrangement with an improved bag clamp to control the dust sources. The two-nozzle arrangement uses an inner nozzle to fill the bag and an outer nozzle to relieve excess pressure from the bag after it has been filled. Depressurizing of the bag is accomplished once filling is completed with the aid of an eductor, which uses the venturi principle to exhaust excess air from the bag at approximately 50 ft^3/min. A pinch valve is then used to open and close the bag exhaust. The bag is slightly overfilled and held in place until the exhaust system depressurizes the bag. After a few seconds, the bag clamp opens and the bag falls from the fill station. The exhaust system continues to operate as the bag falls away, cleaning the bag valve area. The exhausted material is then recycled back into the system.

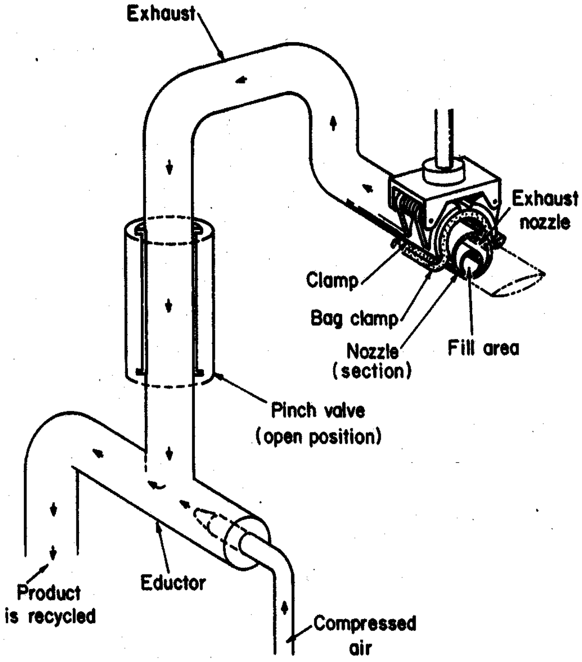

FIGURE 2
Components of a dual-bag nozzle system.

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*Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

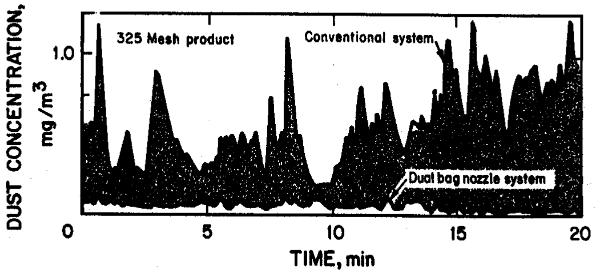

FIGURE 3

Bag operator's dust exposure with and without dual-bag nozzle system while bagging 325-mesh product.

The other key component of the system is an improved bag clamp. This bag clamp makes direct contact with approximately 60 percent of the nozzle, thus reducing the amount of product blowback during bag filling. A controlled amount of blowback is necessary so the bag does not rupture, but this occurs at the bottom of the nozzle, minimizing dust contamination to the outside of the bag.

Several field evaluations were performed to determine the effectiveness of the dual-bag nozzle system.(13) Figure 3 indicates the bag operator's respirable dust exposure with and without the dual-bag nozzle system operating. During these evaluations, the conventional system was initially monitored to establish a baseline before installing the dual-bag nozzle system, and subsequent testing provided a comparison of the reduction in respirable dust at the various monitoring points. One operation achieved an 83 percent reduction in the bag operator's dust exposure with the dual-bag nozzle system. Further, a 90 percent reduction was measured in the hopper below the fill station, indicating a substantial reduction in product blowback during bag filling. In cases where the product is not reused, this results in tremendous product savings.

The use of the improved bag clamp allowed for a significant decrease in the amount of dust and product on the outside of the bag. This resulted in a 90 percent reduction in the bag stacker's dust exposure while bags were loaded into enclosed vehicles.

The dual-bag nozzle system is mainly recommended for operations with three- and four-fill spout bag machines because there is a slight decrease in production due to the time needed to depressurize the bags after filling is completed. The system can be used on a one- or two-spout machine, but this decreases the production rate even further because the bag operator must wait on each individual bag instead of a cycle of bags.

Most manufacturers selling bag filling machines have integrated the dual-bag nozzle system into their new machines. If you are purchasing a new machine, you should ensure that this concept has been incorporated into the unit. If you wish to modify your present bag filling machine, contact your machine manufacturer to determine whether your machine can be modified and to calculate the associated costs. Another option is to perform the modification in-house or through a local engineering company. If you are considering this option, more detailed information about the system can be provided to you by the authors.

Overhead Air Supply Island System

The overhead air supply island system (OASIS) provides an envelope of clean, filtered air to a worker at a stationary location. In testing, the OASIS successfully reduced the respirable dust exposure to both the bag operator and the bag stacker.

One of the main advantages of the OASIS is that it is suspended over the worker and operates independently of any processing equipment (Figure 4). Mill air is drawn into the unit and passes through a primary HEPA cartridge filter. After the air exits the primary filter, it passes through an optional heating or cooling chamber, which can be incorporated in the unit if temperature control is desired. The air then flows through a distribution manifold, which also serves as a secondary filter, and finally exits the unit. The resulting filtered air flows down over the worker at an average velocity of 375 ft/min, which normally keeps any mill air from entering this clean air core.(14) The system can detect a filter overload based upon an increase in pressure and automatically self-cleans the HEPA filter using one of various cleaning techniques, such as reverse pulsing.

The OASIS was evaluated at a number of different operations by comparing a worker's respirable dust exposure with the device turned on and off. Both evaluations discussed in this report were conducted with the unit located directly over a bag operator. Figure 5 compares the bag operator's respirable dust exposure with and without the OASIS device at one field test site. As shown, the bag operator's respirable dust exposure was reduced by 98 percent with the use of the OASIS device. At a second site, an 82 percent reduction in the bag operator's dust exposure was achieved. The reason for the difference between these two plants was that a lower background dust level existed at the second plant. At both plants, the dust concentration with the OASIS operating remained under 0.04 mg/m^3.

An additional benefit provided by the OASIS is that the filtering system provides approximately a 12 percent overall reduction in the mill building dust levels. The volume of clean air delivered by the OASIS is somewhat variable based on the size of the unit but is normally in the range of 6000 to 10,000 cfm. By design, the OASIS is generic and can be fabricated and installed in-house or through any local engineering company that handles ventilation and dust control systems.

Pallet Loading System

The pallet loading system (PLS) is designed to lower the bag stacker's respirable dust exposure when bag palletizing is performed at a stationary location. This system has also ergonomically improved the bag stacking process by reducing the strain placed on the worker while also slightly increasing the production rate.(15)

In the pallet loading system, a push–pull method of ventilation is used to control the dust. Blowing air (push) entrains dust generated during bag stacking and moves it across the top of the

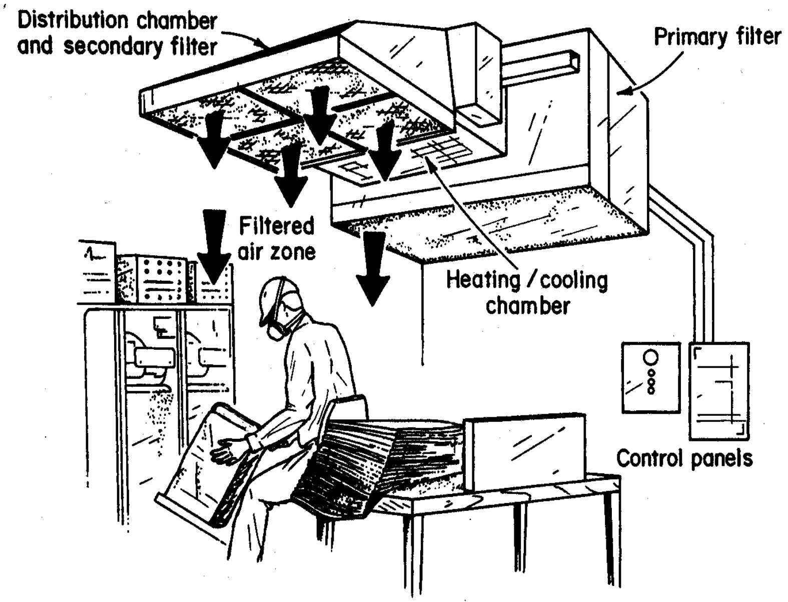

FIGURE 4
Components of overhead air supply island system (OASIS) over the bag operator.

bags until it is captured by the exhaust hood (pull). A number of improvements were made to the push–pull system throughout this research effort. The final design for the push component uses two 3-inch air jets that deliver approximately 120 ft^3/min at an exit velocity of approximately 1200 ft/min. These jets direct air across the top of the bags which is then captured by the exhaust hood on the opposite side of the pallet (Figure 6). The exhaust system pulls approximately 2500 ft^3/min of air, which is normally delivered to a baghouse-type dust collector system.

A critical feature of the ventilation system is that the blowing jets must remain above the height of the bags. Therefore, to ergonomically improve the bag stacking work process, a hydraulic lift table is used that allows the stacking height to remain constant at the best ergonomic height of 28 to 32 inches throughout the entire pallet loading process. With the conventional bag stacking cycle, most potentially harmful lifting occurs during the beginning and ending layers of the pallet. For the beginning layers, the bag stacker must bend down toward the pallet so that the bags do not drop a great distance and break. Loading the top few layers requires the bag stacker to lift the bags and place them high up onto the pallet (Figure 7). The PLS is designed to maintain the loading height at 28 to 32 inches throughout the entire pallet loading process by incrementally lowering the hydraulic lift table by four inches (the thickness of one bag) as each layer of bags is completed. This substantially reduces the strain on the worker and thereby reduces the risk of a lost-time back injury.

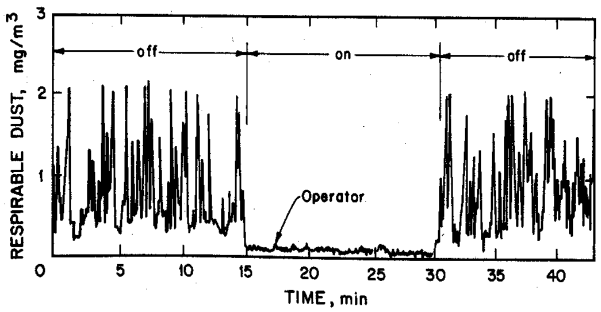

FIGURE 5
Bag operator's dust exposure with and without OASIS.

By improving the ergonomics of the bag stacking process, the bag stacker's fatigue level over the workday is reduced, allowing for a higher production rate. Long-term cost savings are also likely because of the reduction in the number of back injuries, which account for the largest number of lost-time accidents for this job function.

Another benefit the PLS offers is the reduction in downtime between pallets. With the conventional system, after a completed pallet is removed by the forklift, the bag stacker shuts down the conveyor line, carries another pallet into place, and repeats the process. With the hydraulic lift table, four pallets can be loaded without shutting down the conveyor line. When a pallet is full, the forklift removes it and the next empty pallet is already in place for loading to begin as soon as the hydraulic lift table is raised to the loading height. Typically, there is no need to turn off the conveyor and no downtime associated with starting a new pallet; with the PLS, the process only shuts down after the entire stack of pallets is completed. This fact, along with the

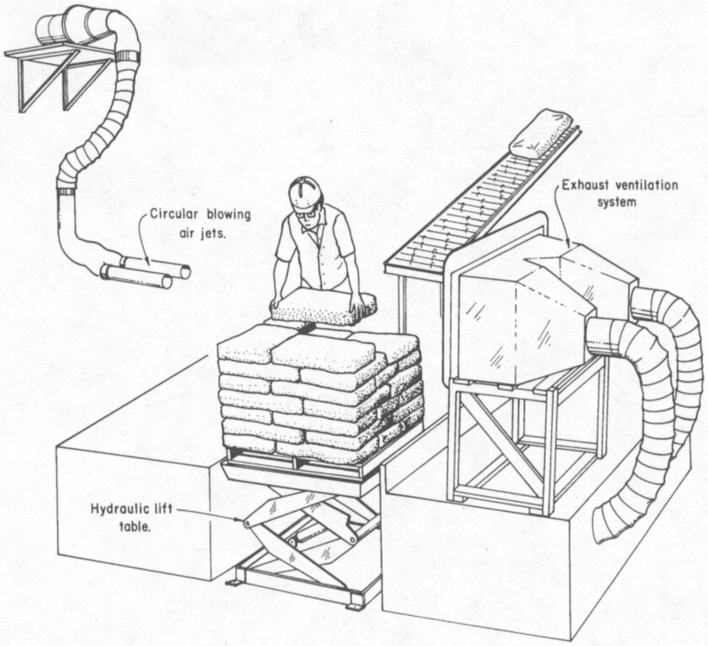

FIGURE 6
Components of pallet-loading dust control system.

bag stacker being less fatigued over the course of the workday, accounts for a measurable increase in production.

The PLS was evaluated at two facilities. At the first evaluation site, one worker performed the entire loading process. This worker loaded the bags with product, removed them from the fill machine, and stacked them onto a pallet located behind him. The effectiveness of the system was measured by comparing dust levels with and without the PLS, as seen in Figure 8. The bag stacker's dust exposure was reduced by 76 percent with the pallet loading dust control system, based on the average off concentration of 0.82 mg/m^3 versus 0.2 mg/m^3 with the system in operation.

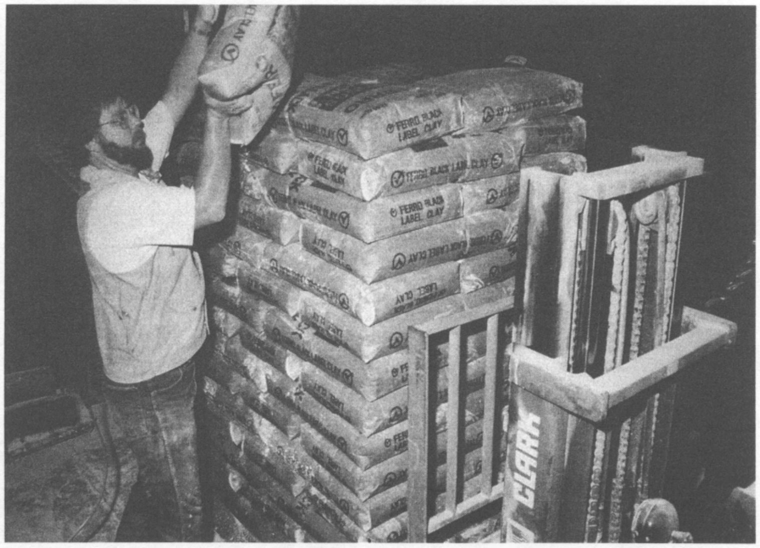

FIGURE 7
Bag stacker lifting bag to load on pallet.

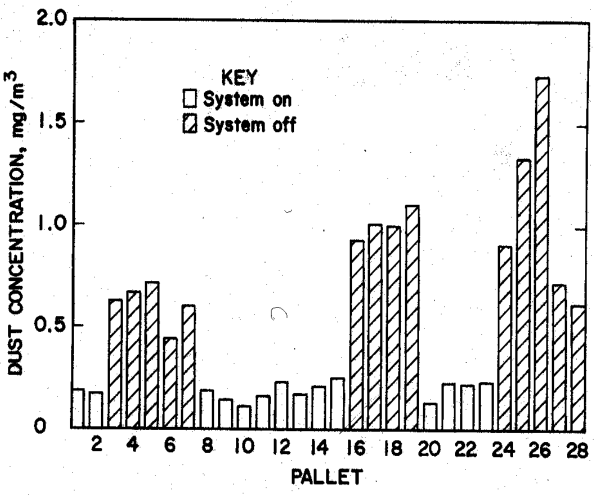

FIGURE 8
Bag stacker's dust exposure with and without the pallet-loading dust control system operating.

At the second evaluation site, two bag stackers loaded bags onto pallets. This plant employed a number of different dust control techniques that effectively removed dust from the bags. Because of these control techniques, the bags were much cleaner, and thus dust reductions were lower with the new system than would normally be expected. Due to lower overall dust levels, the bag stacker's respirable dust exposure averaged a 33 percent reduction.

The PLS can easily be installed at any operation by first fabricating the ventilation ductwork necessary for the blowing and exhaust system. A small fan is necessary for the blowing system and we recommend that the exhaust be handled by a baghouse-type collection system. We also recommend that the operator purchase a hydraulic lift table capable of meeting the loading height and weight requirements of the operation.

Bag and Belt Cleaner Device

The purpose of the bag and belt cleaner device (B&BCD) is to reduce the amount of dust escaping from bags as they travel from the bag loading station to the stacking/palletizer process. This device reduces the dust exposure of all workers in and around the conveying area as well as anyone handling the bags once they are filled.

The B&BCD system is designed to clean the bags and belt after the bags exit the filling station.(16) The system should be applicable to any mineral processing operation that loads product into 50- to 100-lb paper bags. The B&BCD is 10 feet long and cleans all sides of the bag using a combination of brushes and air jets. The system is totally enclosed and under negative pressure to contain all dust removed from the bags and the belt within the device.

Figure 9 shows a bag and belt cleaner device. As a filled bag enters the device, it travels through a door made from heavy-duty flexible plastic stripping and into an air chamber. Inside

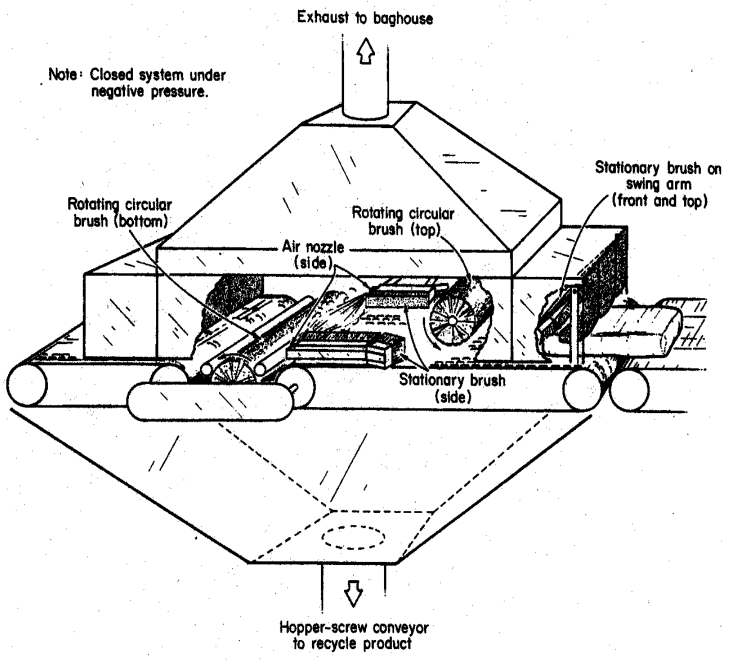

FIGURE 9
Components of bag and belt cleaner device (B&BCD).

the air chamber, a stationary brush on a swing arm starts the cleaning process on the front and top of each bag. The bag then travels through a second plastic stripping door and enters the main section. The bag travels under a rotating circular brush that further cleans the top of the bag. The sides are then cleaned by a stationary brush positioned on each side of the chamber. An air jet is located at the end of each of these brushes to provide additional cleaning, with one air jet at a higher velocity than the other. The bags enter the device so that the valve side, which is normally much more contaminated than the non-valve side, faces the higher-velocity air jet. After passing through the air jets, the bags travel over a rotating circular brush beneath the bag which cleans the bottom of the bag. The bag then exits the device by traveling through another air lock chamber with flexible plastic stripping.

A chain conveyor is used for the entire length of the device to allow product removed from the bags to fall into a hopper. Product collected in this hopper can be recycled back into the process. Once exiting the B&BCD, both the bags and the conveyor belt should be essentially dust-free.

The B&BCD was evaluated at two mineral processing plants. At one operation, the device was tested for two weeks. One analysis technique used during testing was to determine the reduction in the amount of product on the surface of the bags. A specific number of bags were vacuumed with and without the B&BCD to determine the change in the amount of product and dust on the outside of the bags. The average reductions with the B&BCD were as follows:

- 100-lb bags, 200-mesh product: 77.6 percent average reduction;
- 100-lb bags, 325-mesh product: 81.2 percent average reduction;
- 50-lb bags, 200 mesh product; 89.9 percent average reduction.

Mechanically, the B&BCD performed well throughout the evaluation, but a number of possible modifications were noted in the field testing and subsequently implemented in the laboratory.

Once these modifications were made, the improved B&BCD was taken to another operation for a long-term evaluation. The system was initially evaluated for four days and a number of mill locations were monitored using real-time respirable dust instruments. Unfortunately, many bags ruptured while being transported during this evaluation. These bags normally ruptured either during the bag filling process or as they were ejected from the fill station and hit the conveyor. No bags were torn or broken by the B&BCD. Each broken bag generated a tremendous amount of respirable dust into the work environment and significantly affected the evaluation of the B&BCD.

The bag vacuuming procedure was not affected by the broken bags. A specific number of bags were pulled directly from the loading station transfer point and vacuumed before going through the device. In contrast, other bags were taken directly from pallets after going through the B&BCD. Figure 10 shows the results of the different tests. The reduction in the amount of product removed varied from 82 to 93 percent for the various mesh sizes.

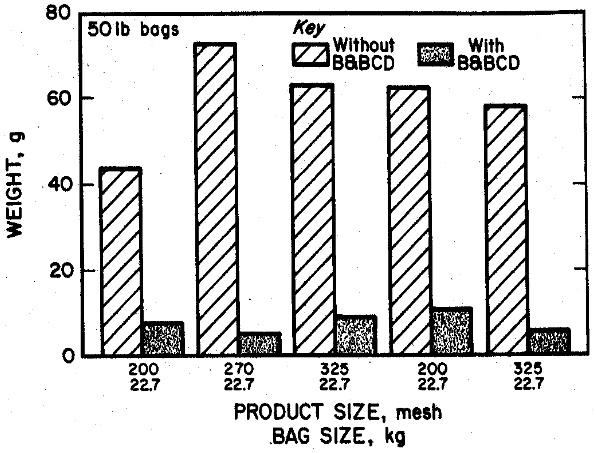

FIGURE 10
Product vacuuming evaluation at second evaluation site for B&BCD.

The B&BCD is designed to be self-supporting so that it can be implemented along the belt line at any operation. There are three installation requirements. The first is to provide 440-V, three-phase electrical power to operate the drive motor for the conveyor and top and bottom circular brushes. The second requirement is compressed air to power the two side-mounted air jets, as well as to operate the pneumatic cylinders that adjust the position of the side brushes to different bag sizes. The third necessity is an exhaust air volume of approximately 1200 ft^3/min, which keeps the system under sufficient negative pressure and prevents dust within the unit from leaking out and contaminating the work environment.

The B&BCD unit could be fabricated in-house or through a local engineering company. A number of manufacturers have either shown an interest in the B&BCD or have begun to manufacture a similar device.

Bag Valve Comparison

The effectiveness of different types of commercially available bag valves in sealing the bag was compared during the filling, conveying, and stacking process. As previously explained in the dual-bag nozzle section, a substantial amount of dust is emitted from the bag valve at various stages in the process. Dust liberated from the bag valve contaminates both the bag operator and the bag stacker.

The bag valve allows the fill nozzle to fit into the bag so that it can be filled with product. When the bag is full and falls to the conveyor, ideally, the product within the bag forces the valve closed and seals the bag to keep product from leaking during transportation. However, because product material is normally trapped in the valve during bag filling and ejection, the valve does not usually close properly. This product material often works its way out of the bag due to vibrations and jarring as the bag moves on the conveyor line or while it is loaded onto a pallet.

Five different valves were tested during this study: standard paper, polyethylene, extended polyethylene, double trap, and foam.(17) By far the most effective valve was the extended polyethylene. This is simply a plastic valve, approximately two inches longer than the standard paper or polyethylene valve. Most bag manufacturers sell the extended polyethylene valve for approximately one to two cents per bag more than the normal paper valve type.

Two factors determined the effectiveness of the bag valve. The first was the valve length—that is, longer valves were more effective in reducing product blowback and bag-generated dust. However, valves that become too much longer than the fill nozzle can start to negatively impact the bag filling performance. The second factor was the valve material, with foam being the most effective. Because foam is an open-cell material, the cells allow the excess air pressure to escape the bag while keeping the product material within. Valve material types listed from most to least effective were foam, polyethylene, and paper.

The foam valve was the shortest valve tested for the evaluation at four inches in length, while the extended polyethylene valve was six inches long. The foam material was very expensive compared to the paper and polyethylene valves, and increasing the length of foam to further improve its performance would only increase its cost even further.

The ranking of valve types from the most to least effective were as follows: extended polyethylene, foam, standard paper, polyethylene, and double trap. Figure 11 shows a comparison of the extended polyethylene and the foam to the standard paper valve. Respirable dust levels ranged from approximately 45 to 65 percent lower with the extended polyethylene as compared to the standard paper valve.

Bagging operators should be aware that changes in product leakage and dust liberation are directly based on the type and effectiveness of the bag valve used in their bags. The extended polyethylene valve was the most effective valve tested in this evaluation, with only a minor cost increase over the standard paper valve.

Indirect Methods for Controlling Secondary Dust Sources

To maintain a healthy work environment and help keep personnel in compliance with respirable dust regulations, plant managers need to consider all plant practices that can contribute to an employee's personal dust exposure. At the Pittsburgh Research Laboratory, we have found that controlling less obvious dust sources can have a major impact on reducing workers' dust exposures. Normally, the dust generated by a worker performing a job function is classified as primary dust. Secondary dust is any dust exposures related to the worker's job function outside of the primary dust sources. To help lower the bag operator's and bag stacker's dust exposure, this section discusses a number of ways to reduce secondary dust sources.

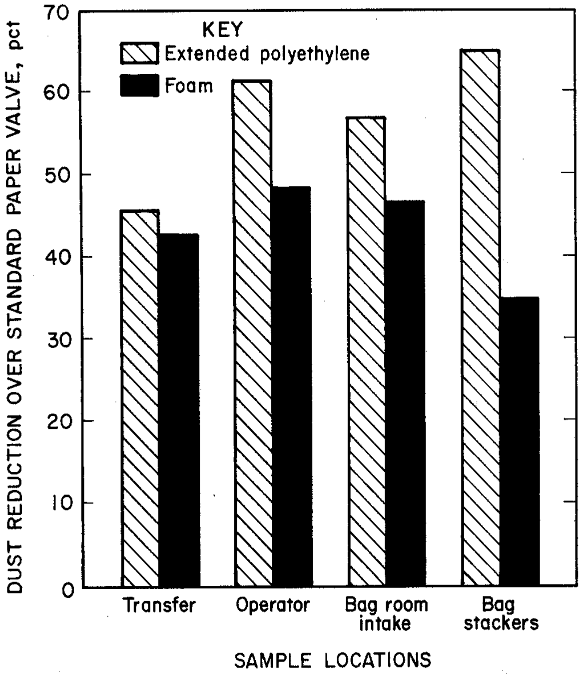

FIGURE 11

Dust reductions with extended polyethylene and foam valves compared with that of the standard paper valve.

Total Mill Ventilation System

The use of a ventilation system called the total mill ventilation system (TMVS) can lower the respirable dust exposure of all workers in a mineral processing building, including the bag operator and bag stacker. Most mill buildings can be considered closed systems; thus, any dust that is not being controlled within the structure will cause dust levels to gradually increase over a given shift. Reducing overall respirable dust concentrations inside the buildings also reduces workers' personal dust exposures.

The TMVS is designed to be a "bottom-to-top" ventilation system.(18) Clean make-up air, brought in at the base of the structure through wall louvers or open doors, sweeps upward through the building, clearing dust-laden areas within the structure. This air is then discharged at or near the top of the building, where it will not contaminate plant personnel working outside. In addition, thermodynamic effects generated by mill equipment produce a chimney effect, assisting the basic flow pattern of this ventilation system.

Two evaluations were performed on the TMVS at working operations. The first evaluation occurred at a clay processing facility where a TMVS was installed, providing 25,500 ft^3/min of ventilating air to the mill building. This air volume represented approximately 10 air changes per hour (acph). Ventilation was provided by three 8500-ft^3/min exhaustors that were evenly spaced across the roof of the mill building. Three wall

TABLE I

Dust reduction for gravimetric and RAM-1 instruments at five monitoring locations for both field evaluations at mill 1, percent

	1		2		3		4		5	
Day	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1
					December evaluation					
1	64.9	54.8	33.3	18.5	40.7	55.0	55.0	53.4	33.5	[A]
2	49.0	18.4	54.2	43.8	40.9	35.0	67.4	55.3	[A]	72.5
					April evaluation					
1	37.4	20.1	66.7	53.5	14.6	22.7	48.7	38.2	53.4	12.1
2	63.3	44.3	27.7	46.3	0	33.3	27.6	37.2	44.8	29.5
3	48.3	16.8	63.5	56.9	27.3	26.2	39.5	35.9	19.2	9.9

[A] Equipment malfunctioned.

louvers were installed to provide an inlet for make-up air near the base of the mill. The louver locations were chosen to provide a good distribution profile of clean make-up air throughout the entire mill.

Two tests were performed at five monitoring locations at this clay processing facility. The analysis was performed by monitoring dust levels for one-hour periods with and without the TMVS in operation. The first test was performed for two days in December, when outside ambient air temperatures ranged from 10 to 40°F, and wind chill temperatures were as low as 2 to −8°F. The second test occurred during three days in April, when outside ambient air temperatures ranged between 50 and 80°F.

Table I lists the percent reduction in airborne respirable dust concentrations, as measured by gravimetric and real-time aerosol monitor (RAM-1) samplers at the five monitoring locations for both weeks of testing. Each value was determined by comparing average concentrations with the TMVS off and on for the entire day of monitoring. For this evaluation, the TMVS averaged almost a 40 percent reduction in respirable dust concentrations throughout the entire mill. Figure 12 shows a three-hour period recorded at one sample location and displays approximately one-hour periods with the system off, then on, then off again.

The second evaluation was performed at a silica sand operation for two, 14-hour days of testing during June. The TMVS was composed of four, 25,000 ft^3/min belt-driven, propeller-type wall exhaustors at the top of the structure. Tests were performed with two and four fans operating. With two fans operating, the TMVS provided 50,000 ft^3/min and 17 acph; with all four fans operating, the system provided 100,000 ft^3/min, corresponding to 34 acph. Table II shows the results with the RAM-1 devices for both days of testing at five monitoring locations. The average reduction in respirable dust concentrations at all five monitoring locations with two and four fans operating were 36.1 and 64.3 percent, respectively.

For the TMVS to be effective, three design criteria must be achieved. First, the system should be capable of supplying clean

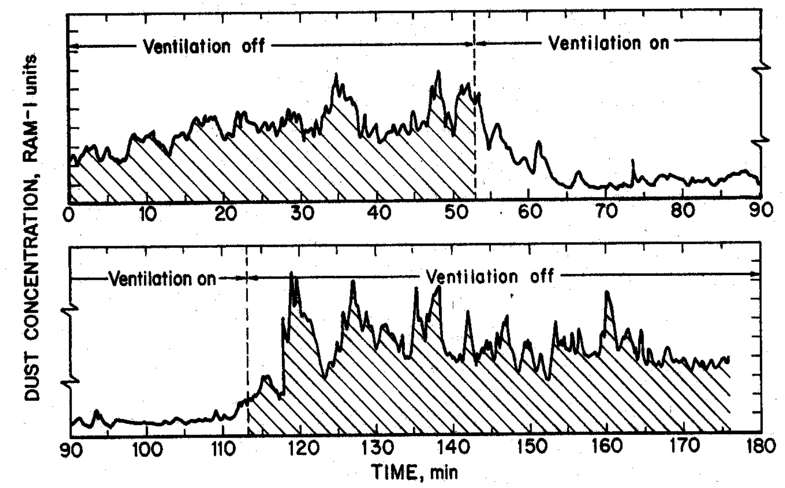

FIGURE 12

Respirable dust concentrations at sample location with and without total mill ventilation system.

TABLE II

Dust concentration and percent reduction for RAM-1 instruments at five monitoring locations at mill 2

	Fan off	Two fans		Four fans		Four fans, windows open	
Location	Concentration, mg/m^3	Concentration, mg/m^3	Reduction, pct	Concentration, mg/m^3	Reduction, pct	Concentration, mg/m^3	Reduction, pct
			Day 1				
1	2.17	1.17	46.08	0.88	59.45	A	A
2	2.53	2.39	5.53	1.35	46.64	A	A
3	2.36	1.43	39.41	.85	63.98	A	A
4	2.04	.92	54.90	.71	65.20	A	A
6	1.92	1.16	39.58	.89	53.65	A	A
			Day 2				
1	2.59	1.69	34.75	1.06	59.07	1.02	60.62
2	3.67	2.10	42.78	1.18	67.85	1.18	67.85
3	3.31	2.13	35.65	.97	70.70	1.35	59.22
4	3.68	2.46	33.15	1.02	72.28	1.68	54.35
6	2.32	1.58	31.90	.61	73.71	1.48	36.21

^{A}No testing performed.

make-up air to the base of the mill. Second, the system needs to provide an effective flow pattern to ventilate the entire mill while providing a sweeping action in the major dust-generation areas. This is achieved by the proper positioning of both fans and make-up air intakes. Proper positioning of air intakes has two purposes: (1) to provide clean outside air, and (2) to provide an effective flow pattern to purge the entire structure. Finally, the outer shell of the structure should be competent, or void of openings that allow air to flow into the structure and impede the desired airflow pattern.

Another consideration when designing a total mill ventilation system is to account for the prevailing wind direction. Wall exhausting fans should not be placed where they will work against the prevailing wind; rather where possible, air should be exhausted with the direction of the prevailing wind. This minimizes the possibility of recirculation or reentrainment of dust back into the structure.

The TMVS is probably the most cost-effective method that an operation can use to lower total mill dust levels. At mill 1, the total cost, which included the ventilation system, installation, and materials, was approximately $10,000. This cost included an outside contractor who performed the installation work. At mill 2, the total cost of the system was approximately $6,000 and the installation work was performed in-house. Relative to cost and performance, no other engineering control technique can yield the dust reductions obtained with the TMVS. Not only are initial costs low, but operating and maintenance costs are also minimal.

Background Dust Sources

A number of common background dust sources were identified that can significantly increase the bag operator's and bag stacker's respirable dust exposure.(19) These background dust sources, which are often unrecognized, can cause even more contamination than the known dust sources from the bag loading and bag stacking process. In some cases, background dust sources were identified that increased the worker's respirable dust exposure five to ten times more than the dust generated from the job function. Given these findings, operators should be aware of the impact and magnitude of these background dust sources.

A few examples of background dust sources demonstrate their impact on the bag operator's or bag stacker's dust exposure. Following these examples, a list of various background sources is provided to indicate the magnitude and extent of the possible sources. We also show how these background sources impacted a bag operator's dust exposure. These findings are also applicable to the bag stacker's position.

Contaminated or soiled work clothing can be a significant background dust source.(20) Figure 13 shows the effects of a bag operator becoming soiled with product from a fill nozzle when

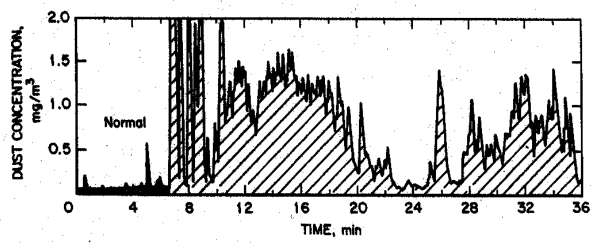

FIGURE 13

Bag operator's exposure from soiled work clothes while changing saddle height.

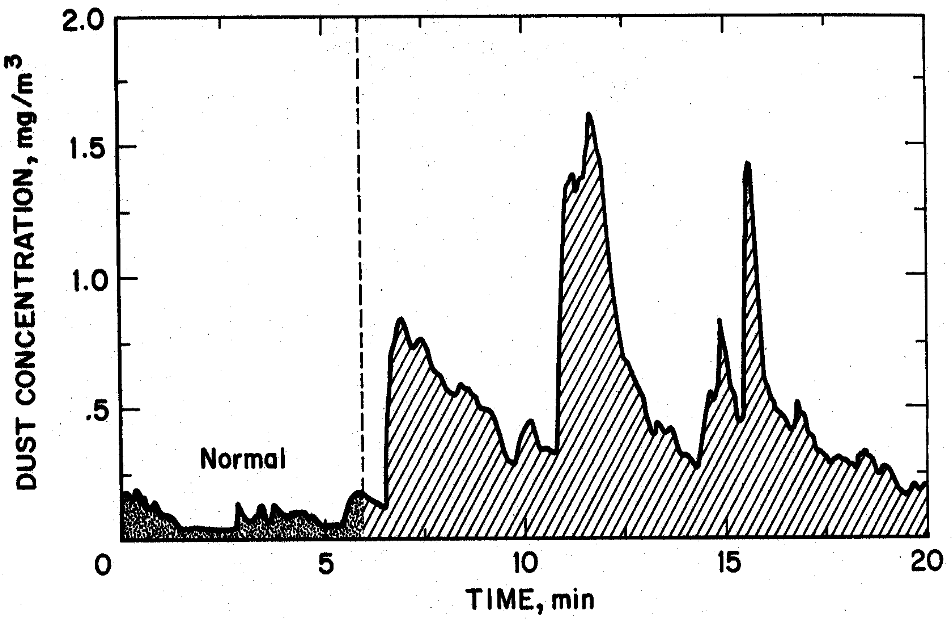

FIGURE 14
Bag operator's dust exposure from a broken bag during the conveying process.

he inadvertently hit the start button with his shoulder while readjusting the saddle height on one of the bag filling stations. When the start button was activated, the fill nozzle started to spew product all over the worker. This occurred at approximately the 7-minute mark on the strip chart. Instead of the worker stopping and vacuuming his clothes to remove all the product, he continued to work. We believe the elevated respirable dust levels from the 7- to 10-minute mark were significantly influenced by dust being liberated into the air. After the 10-minute mark, the elevated levels can be attributed to the dust being liberated from the worker's contaminated clothes. Prior to the occurrence, the worker's average respirable dust exposure was 0.07 mg/m^3; after the occurrence it increased to 1.15 mg/m^3. This increase reflects over 16 times the previous levels.

Figure 14 shows the increase in the bag operator's dust exposure from a broken bag during the conveying process. The worker's exposure increased from 0.07 mg/m^3 before the bag ruptured to 0.48 mg/m^3 afterwards. Although the bag broke during conveying, the dust generated from this occurrence significantly contaminated the mill air, which then flowed into the bagging room where the operator was located. This occurred because there was an exhaust ventilation system in the bag loading area, which created a negative pressure and drew background air in from the mill. It must be noted that clean make-up air is critical at mineral processing facilities, because baghouse-type dust collectors are so common.

Contaminated work clothes can be a major problem for some operations during the winter months when workers wear heavy work coats. Many workers wash their coats only periodically throughout the winter months, and these coats have the potential to be significant sources of personal dust exposure.

Table III shows a number of background dust sources that impact a worker's respirable dust exposure. The table shows the workers before and after dust concentration, as well as the amount of increase in dust levels. It must be remembered that these dust sources are site-related, that is, a significant background source at one plant might be insignificant at another.

It is evident that each of the occurrences and dust sources listed had a significant effect on a worker's dust exposure, and

TABLE III
Nine cases of background dust exposure to bag operator

Description	Dust concentration, mg/m^3 Before	After	Increase factor
Soiled work clothes	0.10	1.01	10.1
Do.[A]	.07	1.15	16.4
Blowing clothes	.19	.45	2.4
Broken bag-fill station	.11	.35	3.2
Do.[A]	.07	.40	5.7
Broken bag-conveying	.07	.48	6.9
Bulk loading outside	.17	.42	2.5
Bag hopper overflowing	.06	.73	12.2
Sweeping floor	.03	.17	5.7

[A] Do. Same as above.

the importance of controlling these sources is clear. In each of these cases, the background dust exposure could be eliminated or at least reduced significantly. Any worker who becomes soiled with product material should immediately vacuum or change clothes. Companies should ensure that workers clean their work garments regularly or company coveralls should be provided. Clothes should not be blown off with compressed air. If broken bags are a problem, changes need to be made through the bag manufacturer. Make-up air into mill buildings should be from non-contaminated areas. Finally, all areas need to be evaluated regularly in an effort to minimize dust exposures to workers.

Personal Work Practices

A worker's dust exposure can be impacted by personal work practices. During an evaluation of a dust control system at one processing plant, substantial variations existed in the dust exposures of two workers performing the same job based on differences in individual work practices or techniques. During this evaluation, a number of factors were identified.(21)

FIGURE 15
Bag operator crimping bag valve closed after removing bag from fill nozzle.

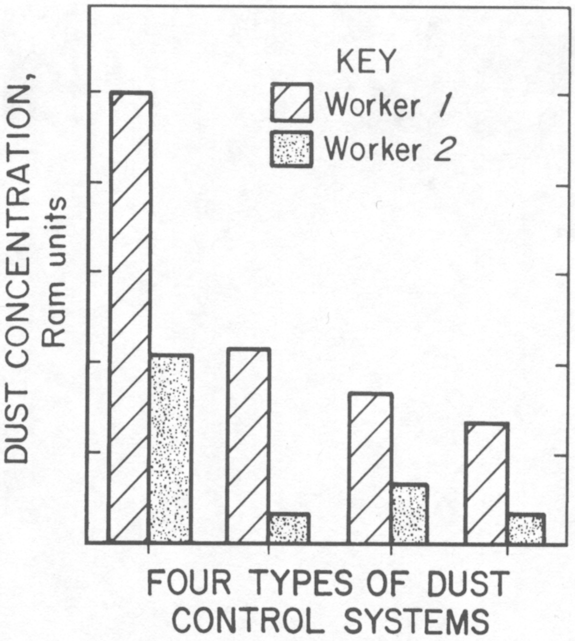

FIGURE 16
Variation in respirable dust exposure from two workers performing the same tasks.

One factor was the amount of time the bag operator allowed the bag to remain on the fill spout before removing it. When the bag was allowed to remain on the fill spout for a few seconds after it was filled, less dust was generated from the rooster tail of product that spewed from the bag valve and fill nozzle as the bag was removed. When the operator maintained a rotation that allowed each bag to stay on the nozzle for a few seconds before removal, an identical production rate could be maintained with substantially less dust generation.

A second factor was the extent to which the bag valve was sealed by the bag operator. One operator paid no attention to where he grasped the bag as he lifted it from the fill spout and turned to place it on the conveyor. A second operator grasped the bag at the fill spout and crimped it closed as he placed the bag on the conveyor (Figure 15). This substantially lowered the amount of product that spewed from the bag as it was placed on the conveyor. It also reduced the amount of product that leaked from the bag as it traveled along the first few feet on the conveyor.

A third factor impacting the operator's dust exposure was the manner in which the operator removed the bag from the bag spout and placed it on the conveyor. More dust is generated when this is done in a forceful, rough manner, rather than in a more fluid, gentle fashion. Figure 16 shows the impact of these loading practices on the dust exposure of two bag operators when four different dust control systems were being tested. Regardless of the effectiveness of the dust control system, worker 1, who failed to use effective loading practices while performing this job function, consistently had higher dust exposures. Worker 2 was much more conscientious while performing these duties; therefore his overall dust exposure was about 70 percent lower than that of his co-worker.

DISCUSSION AND CONCLUSION

This article provides readers with methods to lower the dust exposure of the bag machine operator and bag stacker. Over the past two decades, bag machine operators and bag stackers have averaged the highest respirable dust exposures of all workers at mineral processing plants. The health risk for these workers becomes even more magnified when products are processed and bagged with a high silica or quartz content, thus increasing the potential for developing silicosis or other serious lung diseases. This article provides the findings of a substantial research effort performed at NIOSH's Pittsburgh Research Laboratory to minimize the bag machine operators and bag stacker's dust exposure while performing these two job functions.

The first portion of this article discusses direct methods for controlling the bag machine operator and bag stacker's dust exposure. The dual-bag nozzle system reduces the dust that is generated during the bagging process, thus lowering the bag machine operator's dust exposure. The OASIS is a device that is placed above the bag machine operator and delivers an envelope of clean air down over the worker, thus lowering his or her dust exposure. The dual-bag nozzle system and OASIS are both engineering controls that have successfully reduced the bag machine operator's dust exposure by 80 to 90 percent.

The pallet-loading dust control system and the bag and belt cleaner device are both engineering control systems that significantly reduce the amount of dust and product on the outside of the bags of product material. Lowering the amount of dust and product on the bags directly correlates with lowering the dust exposure to the bag stacker. The pallet-loading dust control system uses a push–pull ventilation technique to capture and remove the dust generated during the pallet loading process. Through the use of a hydraulic lift table, the system also ergonomically improves the bag stacking process, lowering the stress and fatigue placed on the bag stacker. The bag and belt cleaner device mechanically cleans the bags of product as they travel from the fill to the pallet loading station. With cleaner bags, the bag stacker's respirable dust exposure is significantly reduced during the bag palletizing process.

The last area discussed in the direct methods section was an evaluation of different commercially available bag valves. This study showed substantial reductions in both the bag machine operator's and bag stacker's dust exposure based upon the type of bag valve being used. The extended polyethylene valve was the most effective bag valve tested and provided respirable dust reductions above 60 percent to both the bag machine operator and the bag stacker at a very minimal cost increase.

The last portion of the article discusses indirect methods for controlling the bag machine operator's and bag stacker's dust exposure. Secondary dust sources have been shown to have a tremendous impact on affecting these two job functions. Being aware and controlling these secondary dust sources can have a very positive effect on lowering a worker's dust exposure. One secondary dust source is high overall dust levels throughout an entire mill building where the bag filling and stacking is performed. The total mill ventilation system is a very cost-effective method for controlling this problem and lowering all workers' dust exposure in the mill building. The total mill ventilation system uses a bottom-to-top concept that brings clean air in at the base of the mill building and pulls it up through the building by mechanical fans placed on or near the roof of the structure. This system has been shown to reduce respirable dust concentrations by 60 percent at one of the field evaluation sites.

The last two areas discuss background dust sources and personal work practices. Both of these areas deal with how secondary dust sources can have a tremendous impact on a worker's personal dust exposure. One example is contaminated work clothes. There have been a number of documented cases where a worker's clothes were contaminated with product material and increased his or her dust exposure over 10 times previous dust levels. Another area of significant variation in dust exposure is from personal work practices. In one particular study, a bag machine operator who performed his job function in a very conscientious manner was shown to have a 70 percent lower respirable dust exposure than a co-worker who performed the job in a much rougher and careless manner.

It must also be remembered that bag machine operators and bag stackers are exposed to multiple dust sources, and as a result, multiple controls may be needed to lower dust exposures to acceptable levels. By providing a wide spectrum of dust control research performed over the years regarding these two job functions, this article gives industrial hygienists, plant managers, engineers, and workers a vast array of options to pursue in an effort to lower respirable dust levels. In addition, a key factor in providing long-term protection for workers is ensuring that control technology is operating properly through a diligent maintenance program. The synergistic effect of combining the type of dust control techniques discussed in this article with a holistic industrial hygiene program should result in lowering the incidence of silicosis and other fibrotic lung diseases for bag machine operators and bag stackers at mineral processing operations. As we continue to move toward our goal of ensuring the safety and health of the working men and women of this nation, it is critical that better dust controls be implemented in the bag machine operator and bag stacker job functions.

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