Improving Silica Dust Controls for Metal/Nonmetal Mining Operations in the United States

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Abstract

Researchers at the Pittsburgh Research Laboratory (PRL) of the National Institute for Occupational Safety and Health (NIOSH) work to reduce respirable dust exposures in mining operations. One focus of this research is silica dust control for surface and underground operations in the metal/nonmetal mining industry. PRL researchers analyze dust sampling results from the Mine Safety and Health Administration (MSHA) to identify high-risk occupations to guide research efforts. Research is then conducted in an effort to improve existing technologies and/or develop new controls for reducing worker exposure to airborne silica dust. During the last few years, PRL researchers have conducted research related to the following goals: improving protection provided by enclosed cabs on mobile surface mining equipment, reducing dust generation from surface drills, reducing dust levels in iron ore operations, and developing a new method to clean dust from workers' soiled clothes. A description of each of these controls and subsequent dust reductions quantified through site surveys will be provided.

Background

Overexposure to respirable silica dust can lead to the development of silicosis, a debilitating and potentially fatal lung disease. Consequently, exposure to silica dust is limited by regulations enforced by MSHA. When MSHA suspects that silica dust may be present in a metal/nonmetal mining operation, a gravimetric sample of the respirable fraction of airborne dust is collected. This sample is then analyzed for silica content using X-ray diffraction. If the percent of silica in the sample exceeds 1%, a respirable dust standard is calculated by dividing 10 by the (% silica + 2). For example, if a sample contains 8% silica, the respirable dust standard would be 1.0 mg/m^3 $[10 \div (8+2)] = 1.0]$. If the dust concentration of the collected sample exceeds this limit, the sample is out of compliance.

NIOSH routinely examines MSHA compliance sampling data in order to identify occupations that are at elevated risk of overexposure. Research is then directed toward identifying and implementing controls that improve the dust protection for these high-risk workers. In addition, NIOSH interacts with stakeholders representing industry, labor, academia, and government and receives input into areas of concern. This input is also utilized in determining the direction of research. As a result, NIOSH researchers conducted research to address silica dust control for enclosed cabs on mobile equipment, rotary surface drills, an iron ore processing plant, and cleaning workers clothes in a silica sand processing plant. Details from this research follow.

Filtration Systems for Enclosed Cabs

Potential worker exposure to respirable silica dust is common in surface metal/nonmetal mining operations, since a significant portion of the overburden contains high silica-bearing strata. Many of the workers at these mines operate mobile equipment that is equipped with enclosed cabs. Unfortunately, a substantial portion of this equipment is old and may not provide the desired protection to the equipment operators. As enclosed cabs get older, gaskets and seals can deteriorate to a point where they no longer provide adequate sealing. Also, older cabs may not have filtration and pressurization systems, or they have poorly designed systems that are incapable of maintaining acceptable air quality within the cab. In an effort to improve the protection provided by enclosed cabs, NIOSH retrofitted filtration and pressurization systems to a haul truck at an underground stone mine and a surface drill at a silica sand operation (Chekan et al., 2003).

At the underground limestone mine, a haul truck that had been manufactured in 1975 was selected for evaluation. This truck was used to load fines from the processing plant, transport these fines to different locations, dump the fines, and then return to the plant for the next load. This truck was fitted with a heating and air-conditioning unit that had minimal dust filtering capabilities. This unit was mounted inside the operator's cab on the roof.

For this study, the original air-conditioning system on the haul truck was replaced with an external unit mounted on the top of the cab. The new system included heating, cooling, and pressurization, with high-efficiency filter media for both the pressurizer filter and the final filter in the recirculation unit. These filters were rated at 99% efficiency for particles greater than 0.5 microns. In addition, the integrity of the enclosed cab was improved by replacing the door seals with foam weather stripping and sealing gaps in the cab with caulking.

Gravimetric dust samplers were operated within the cab and outside of the cab directly below the operator's front windshield. Sampling was conducted for three shifts with the original equipment and then three shifts after the new filtration system was installed. Silica content of the samples from each shift was determined with X-ray diffraction. The data was then averaged for each of the test conditions and is summarized in Table 1. As shown, installation of the new filtration system made a significant improvement to the protection afforded by the enclosed cab.

Table 1. Average dust concentrations at the haul truck with each filtration system.

Test Condition	Average Respirable Dust Concentrations			Average Respirable Silica Concentrations		
	Outside Cab mg/m^3	Inside Cab mg/m^3	Reduction, %	Outside Cab mg/m^3	Inside Cab mg/m^3	Reduction,%
Baseline	0.425	0.279	34	0.035	0.023	34
Retrofit	1.010	0.317	69	0.071	0.017	76

It should be noted that the dust conditions outside of the cab for all three days of testing during retrofit sampling were as least twice as high as the baseline testing. These higher concentrations influence the amount of dust actually penetrating the cab and resulted in slightly higher dust levels inside the cab with the retrofit system. However, if the interior dust levels from the retrofit testing were normalized for the outside concentrations from the baseline levels, a 52% reduction in respirable dust and a 63% reduction in respirable quartz dust in the cab are achieved with the new system. This is a measure of the actual improvement in the cab working environment that could have been expected if outside dust levels had been equal.

A second study was completed on a rotary drill at a silica sand surface mine. Similar to the haul truck, a new filtration and pressurization unit was installed on the roof of the cab to replace the original filtration system. Gravimetric sampling was conducted inside and outside of the cab to compare the protection provided by the original filtration system to that of the retrofitted system. Sampling results indicated that the dust levels outside of the cab again differed significantly between the testing of the original and new systems. After normalizing the dust concentrations measured inside the cab for the differences observed outside, the new system reduced dust levels in the cab by 67%.

The original filtration system was tested during the winter months. With this system, heat to the cab was supplied by a heater located on the floor of the cab, as shown in Figure 1. During testing, it appeared that the floor heater was creating higher dust levels in the cab by blowing air across the dirt tracked into the cab on the operator's boots.

Figure 1. Floor heater in surface drill cab.

The drill was taken into the shop and particle counting instrumentation used to evaluate the filtration system and floor heater. The optical particle counting results indicated that the floor heater raised respirable dust levels from 0.03 to 0.26 mg/m^3 in the shop tests. The new filtration/pressurization had heat supplied at the roof of the cab, allowing for elimination of this floor heater and the internal dust source. This testing also illustrated the importance of having a filtered recirculation circuit that will remove dust generated inside of the cab.

Surface Drill Dust Collector

MSHA compliance sampling data has historically shown that drill operators at surface mines are typically at the highest risk of being overexposed to respirable silica dust. As a result, NIOSH has examined methods to lower the dust levels liberated by surface drills. The information already discussed for enclosed cabs also has direct application.

The majority of the surface drills being operated in the United States are equipped with dry dust collectors. Typically, these drills have the inlet to the dust collector located at the rear corner of the drill table and are designed to collect airborne dust as it is blown out of the drill hole by the bailing airflow. NIOSH has conducted laboratory research to evaluate the relationship between the bailing airflow and the collector airflow for these systems. In addition, NIOSH designed a modified collector inlet that moves the inlet around the drill stem. Preliminary tests were conducted on the modified hood design to ensure that larger drill cuttings would not accumulate in the hood and that the inlet could provide an effective seal around the drill steel. A deflection plate was designed with a triangular top section that traversed the circumference of the plate inside the hood surrounding the drill stem. This was intended to be self-cleaning so that any larger sized material making it inside the hood could slide back out through the perimeter of the hood inlet gap. A rubber seal (made out of conveyor belting) was utilized to seal the deflection plate gap around the drill stem. Figure 2 shows a standard and the modified collector inlet.

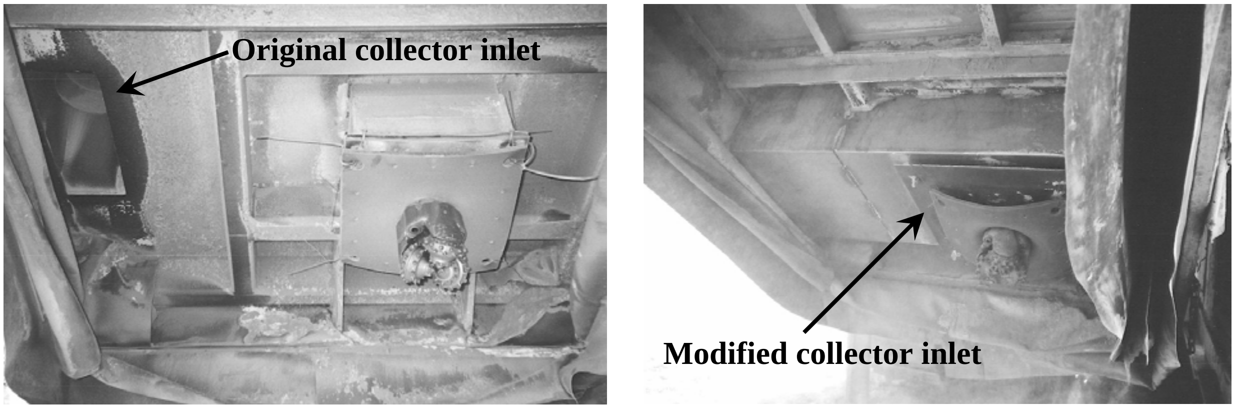

Figure 2. Original and modified collector inlet locations.

Laboratory experiments were conducted to evaluate three factors that impact dust liberation: 1) the amount of open area or bottom gap between the ground and drill table shroud, 2) the dust collector airflow to bailing airflow ratio, and 3) the collector inlet location. Since down-the-hole bailing airflow is usually set for maximum drill penetration rate and bit cutter life, varying this parameter over a broad operating range for dust control is usually not a functional consideration. In the lab experiments, the drill hole bailing airflow was set at a constant flow rate and the collector airflow was changed to achieve the desired collector to bailing airflow ratio. The drill hole bailing airflow varied between 170 and 179 L/s to yield a bailing air velocity between 23.4 and 24.9 m/s, representing typical drilling conditions found on medium sized drills in the US.

These tests were conducted in a large, 3.66-m wide by 3.05-m deep by 2.44-m high dust chamber. The simulated drill shroud was located in the center of the dust chamber with the dimensions of 1.52-m wide by 1.22-m deep by 1.22-m high. This shroud size is within the range found on medium-sized, rubber tire or track-mounted rock drills, typically drilling holes 12.7 to 20.3 cm in diameter with about 178 kN to 222 kN of drill pull down pressure.

Laboratory tests were conducted to evaluate a range of operating parameters (Organiscak and Page, 2005). The ground-to-shroud gap was varied from a minimum of 5.1 cm to a maximum of 35.6 cm. The dust-collector-to-bailing-airflow ratio was varied from a minimum of 2:1 (collector volume of about 349 L/s) to a maximum of 4:1 (collector volume of about 698 L/s). The baseline tests were conducted with the collector inlet located toward the back corner of the drill table. Tests were also conducted with the inlet relocated above the drill hole. Figure 3 illustrates the dust levels measured for the different operating conditions.

Laboratory testing showed that the inlet hood concept notably improved drill dust collector system capture over the conventional inlet location, particularly with large leakage areas at the

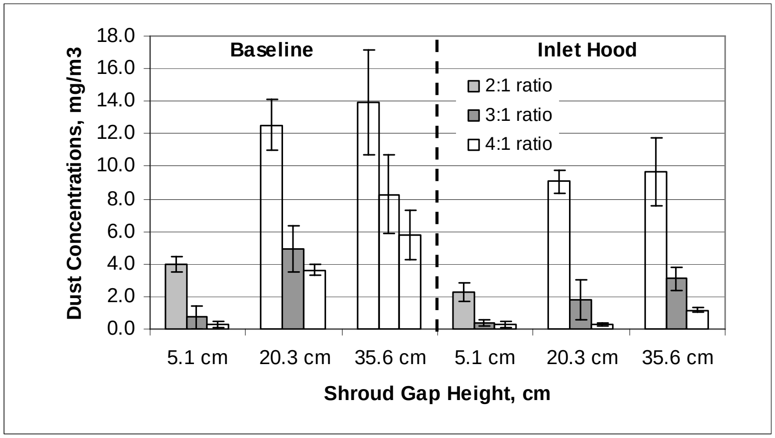

Figure 3. Laboratory dust concentrations escaping the shroud for different test configurations.

bottom of the shroud enclosure. The most significant improvements were between 63 and 91% dust reductions measured at collector-to-bailing airflow ratios of 3:1 and 4:1 with shroud gap heights of 20.3 and 35.6 cm. The laboratory tests also showed that the two key influential factors on collector inlet capture were the collector-to-bailing airflow ratio and the shroud gap height for both inlet configurations. Nearly an order of magnitude increase in dust leakage was observed when the shroud gap height was increased from 5.1 to 20.3 cm with the conventional inlet configuration. The higher collector-to-bailing airflow ratios and inlet hood configuration mitigates this dust leakage at the higher shroud gap heights (20.3 and 35.6 cm, respectively).

Given the laboratory results measured with the modified inlet hood, field testing was conducted to examine its operational viability and performance. The field study plan was to conduct area dust sampling around the drill shroud in its existing state for several shifts and resample after the inlet hood was installed. The inlet hood had to be significantly redesigned from the laboratory version to custom fit this particular drill deck underside

The shroud enclosures used on all the drills at this mine were an angle curtain design that could be hydraulically raised and lowered to seal with uneven ground surfaces. During the initial visit to the mine, the shroud on the test drill had signs of wear that allowed dust to leak out. However, a day before the baseline study began the drill was serviced, including dust filter replacement and repair of the shroud holes. After the shroud was repaired, it maintained a good seal with the ground, with average dust levels outside of the shroud equal to 0.18 mg/m^3 during baseline testing. These findings support the data from the laboratory tests that illustrated the benefits of a sealed shroud.

In spite of the low baseline dust levels, the inlet hood was installed to examine its operational functionality, since the inlet hood had been custom designed to fit this particular drill. The modified inlet hood appeared to have a slight but negligible dust reduction to 0.11 mg/m^3. During installation, the drill's bailing airflow was measured to be 380 L/s with collector airflow of 1008 L/s. Immediately after the inlet hood installation, the collector airflow dropped to 963 L/s. From an operational perspective, over 1,500 m of drilling was conducted with the inlet hood installed. Follow-up phone discussions with the mine about the inlet hood's operating status indicated that the inlet hood ductwork eventually filled with cuttings after a week of operation.

To rectify this problem, future hood designs would need to be self-cleaning or have access for manual cleaning to be viable for long-term operation.

Dust Control at an Iron Ore Processing Plant

NIOSH was contacted by stakeholders that expressed interest in lowering dust levels in the grinding and concentrator mill portion of an iron ore processing plant. This multi-level plant had a generally open structure with steel grating separating the different levels of the plant. During the winter months, the plant processed hematite ore with the doors and other air intakes into the plant closed. The hematite typically contained silica in the range of 10–15% and airborne respirable silica was a concern. Therefore, the plant maintained a mandatory respirator zone in the region of the 12 primary grinding mills located at the north end the plant. Figure 4 illustrates the general layout of the grinding and concentrator building.

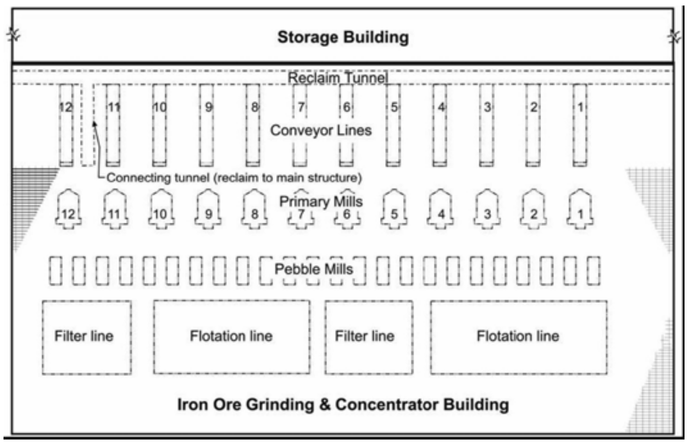

Figure 4. Location of major processes in grinding and concentrator building.

The ventilation provided to this building was through a network of over 70 roof fans that could be operated in either an intake or exhaust mode. In addition to the roof-mounted fans, each of two air heaters supplied 4,250 m^3/min of heated intake air into the basement of the structure, one on the eastern and the other on the western side of the structure. The ventilation setup at this facility changed somewhat over the course of the year based on outside air temperatures. Typically, the air exhausted from the structure was reduced during the winter months, with the goal of providing enough ventilation to remove contaminants while trying to maintain an adequate temperature within the structure.

It appeared to NIOSH researchers that the ventilation fans were being operated in a random fashion, with significant imbalance between intake and exhaust air (Cecala et al., 2006). Gravimetric and instantaneous dust samplers were used at numerous locations throughout the plant during a baseline dust survey to quantify airborne respirable dust levels under typical operating conditions. NIOSH then requested that the number and pattern of operation for the fans be changed to induce a more balanced, directional flow of air through the plant.

The original ventilation setup included 12 exhaust fans operating in the primary grinding area, nine exhaust fans and three intake fans operating in the pebble mill area, and 19 exhaust fans operating in the filter and flotation area. The only other mechanical ventilation provided was from two intake heaters located at the base of the facility. Figure 5 illustrates the relative location of the fans and the original operating pattern. The volume of air being exhausted from the structure was 54,670 m^3/min, as compared to 17,000 m^3/min being brought into the structure. These ventilation air volumes were calculated based upon the rated fan capacities and the assumption that all the fans were operating at their rated output.

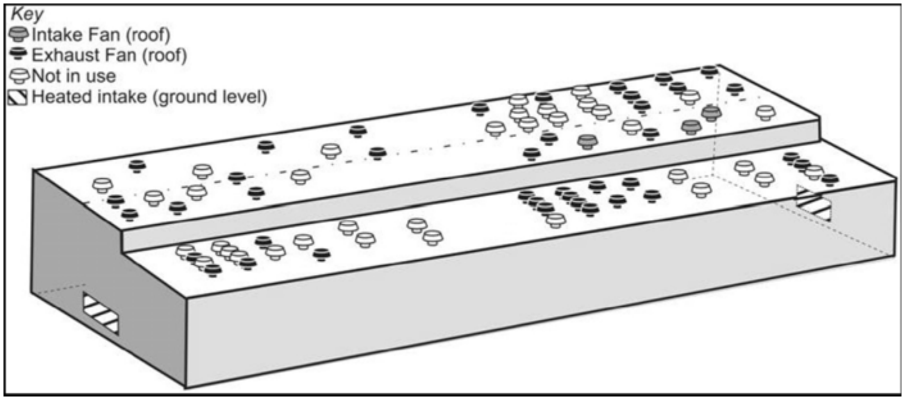

Figure 5. Roof fans at iron ore plant.

Since the baseline sampling data showed that the highest dust levels were observed around the primary grinding mills, fan operation was reconfigured to direct airflow from the southern region of the plant toward these grinding mills. Two different fan configurations were tested with this goal in mind. The final and most effective ventilation setup was composed of 24 exhaust fans and 12 intake fans, along with the two heater intake fans. The volume of air exhausted from the structure was approximately 32,000 m^3/min, with 29,600 m^3/min being brought into the structure through the roof intake fans and two heater fans. This operating pattern resulted in a 31% dust reduction (1.01 mg/m^3 to 0.70 mg/m^3) at the six sampling stations located along the primary grinding mills. Dust levels near the pebble mills and flotation cells were within 0.02 mg/m^3 of levels observed during baseline sampling. This improvement is especially significant because it was achieved simply through better utilization of an existing control technology.

Clothes Cleaning Booth

Past research (Cecala and Thimons, 1986) has shown that dust-soiled work clothes can be a substantial source of personal dust exposure for workers. Currently, the only approved MSHA method for cleaning soiled clothes is to use a HEPA filter vacuuming system. To perform this technique, a worker uses the vacuum hose and manually moves the nozzle over his/her soiled clothing in an attempt to remove the contaminant. Because this task is difficult and time-consuming, some workers choose to use a compressed air hose to blow dust from their work clothing, even though this is not an approved method of cleaning. For either method, the most difficult task is to clean the worker's back and legs effectively.

NIOSH worked with a leading silica sand producer to develop the clothes cleaning booth as an improved method to cleaned soiled work clothes (Pollock et al., 2006). An enclosed booth was purchased and installed at the silica sand plant to provide a worker sufficient space to effectively perform the cleaning operation. Above the door was an open grate that served as an intake for the ventilating air. A return air plenum located on the bottom-back wall of the booth was ducted to the mill baghouse dust collector system, to provide a constant flow of air through the booth. The exhaust flow rate was measured at 2.17 m^3/sec. The booth had a negative differential pressure of 37.3 Pa, which prevented dust leakage from the booth into the plant.

An air nozzle spray manifold was installed in the booth and used compressed air to remove the dust from workers' clothes. The air spray manifold was fabricated from 63.5mm, schedule-40 steel pipe that was capped at the base. Twenty-six flat fan air nozzles were mounted along the manifold, spaced on 50.8 mm centers. The bottom nozzle was a circular design located 152.4 mm from the floor. This nozzle was used in coordination with a ball-type adjustable fitting that was directed downwards to clean the individual's work shoes or boots. At a pressure of 206.8 kPa, the air spray manifold system expels 4.7 m^3 of air for the typical cleaning period. The air spray manifold was actuated by the worker operating a timer-set pneumatic valve located on the top of the manifold. The pneumatic valve had a safety interlock that would automatically shut the air supply to the manifold if the exhaust ventilation system failed to keep the booth under sufficient negative pressure. In order to supply this compressed air volume to the air nozzles for effective cleaning, a 0.45 m^3 reservoir tank was used and typically pressurized to 1,034.2 kPa. The air reservoir was located directly behind the cleaning booth and hard-piped to the air spray manifold located inside the booth. Supply air to the manifold was regulated down to 206.8 kPa. The air regulator was located in a lock-box enclosure to prohibit anyone from tampering with the air pressure. The worker performing the cleaning process is required to wear a half-mask fit-tested respirator with an N100 filter, hearing protection, and full-seal goggles.

Performance of the booth was compared to that of the approved HEPA vacuuming method and using a compressed air line. Each test was timed by a stopwatch to determine the actual cleaning time. Results of testing indicated that the manifold cleaned the clothes at least 10 times faster and removed 50% more dust than the single air nozzle or vacuuming methods. The average cleaning time with vacuuming, the air hose and the cleaning booth was 372, 178, and 18 seconds, respectively. These values represent averages calculated for two NIOSH test personnel, two types of coveralls, and a total of 96 tests. Figure 6 shows the relative effectiveness of the cleaning techniques tested.

Conclusions

These NIOSH research efforts have identified a number of control technologies that can be implemented to reduce the dust exposure of mine workers in the metal/nonmetal industry. All of the controls were demonstrated at mining operations to provide guidance for their application at mining sites. However, a key factor in the success of applying any of these controls will be continued attention to operating details and maintenance of the controls. Too often, NIOSH has observed less than optimal performance from proven control technologies as a result of ineffective maintenance procedures. Likewise, mine workers must be made aware of the importance of properly utilizing dust controls in order to protect themselves on a daily basis from exposure to respirable dust.

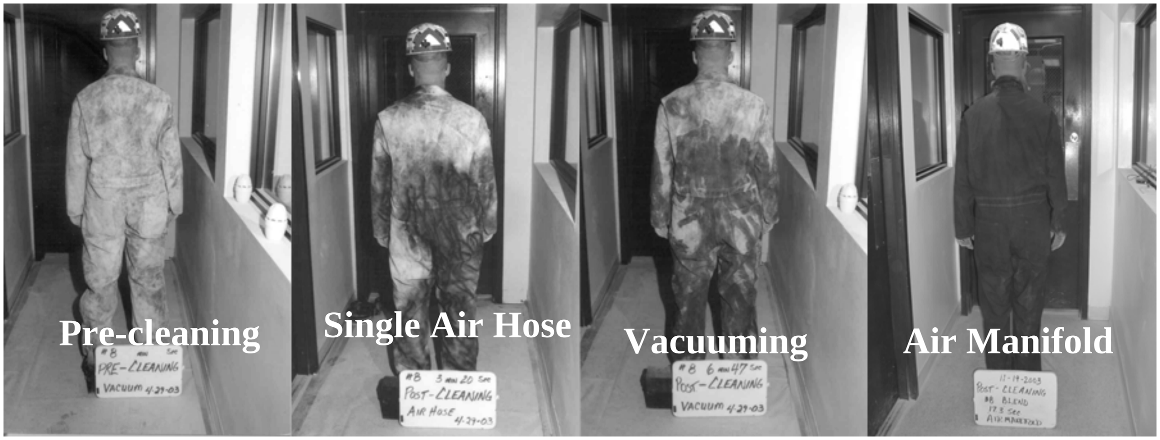

Figure 6. Effectiveness of various cleaning methods.

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