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The future of cab filtration, HVAC design, and operator respiratory health

By Jeff Moredock

The case for the osha silica regulation and its impact on mobile HVAC design

"Why does the OSHA Silica regulation exist?" To protect workers from the dangerous effects of respirable crystalline silica. Silica, which comprises roughly 29% of the earth's surface, interacts with earth-moving equipment whenever rock is crushed, abraded, or cut. According to the National Institute for Health, "Respirable crystalline silica . . . was reclassified in 1997 as a Group One carcinogen by the International Agency for Research on Cancer (IARC)." For us non-medical types, this means there is sufficient evidence suggesting respirable crystalline silica causes cancer in humans. See Figure 1.

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Figure 1: This image of human lungs shows a healthy lung on right and one with silicosis on left. OSHA requires employers to protect their workers from exposure to RCA (respirable crystalline silica), tiny particles that can travel deep into workers' lungs and cause silicosis, an incurable and sometimes deadly lung disease.

Silica exposure, while operating from within a machine cab, is addressed in the regulation. Specific engineering controls, which include a functioning HVAC system, continuous cab pressurization and a minimum level of filtration efficiency (95% on 0.3 to 10 µ particles e.g. MERV 16), are requirements of the regulation.

Merv 16 explained

Many mobile HVAC manufacturers and technicians are not familiar with the Minimum Efficiency Rated Value (MERV) rating system. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) is an association that provides, among other things, a standard testing and rating system (ASHRAE 52.2) for filters produced for commercial buildings and homes. Under its rating system, the lowest efficiency filters are rated MERV 1, while the highest efficiency filters are rated MERV 16.

Why did OSHA apply a standard used for commercial building filtration to an operator cab on a piece of heavy equipment? While far from a perfect fit, the ASHRAE 52.2 testing and rating standard proved to be the best measure available. The test results show a range of particle sizes and the efficiency of the filter within each particle size range.

The National Institute for Occupational Safety and Health (NIOSH) studied cab filtration. One conclusion was, with few exceptions, that filtration used on operator cabs allowed significant concentrations of dust to aggregate in the operator cab. Up to that point, the focus of HVAC filtration was to keep large contaminants and objects off the evaporator core. The filtration acted more as a barrier to fingers, leaves, shop towels, and anything else in the operator cab that could be drawn into the recirculation system.

Filters are often not marked according to any standard rating system, and are often simply promoted as good, better, and best. In the heavy equipment industry, filtration efficiency is determined through the use of an engine filter efficiency test. This test standard produces an efficiency rating based on testing with ISO fine or course test dust, and includes the dust holding capacity of the filter.

Engines require efficient air filtration to keep dust from entering the engine, contaminating the oil, and causing engine wear. When the engine oil gets contaminated it is changed. Human lungs, on the other hand, are negatively affected by small particles and are not easy to change or clean. Therefore, the efficiency of the filter had to improve dramatically to be effective in protecting the machine operator. This necessitated a change in filter testing standards to ensure that the filter is efficient enough for human respiratory environments.

While many factors are important to produce and maintain a clean air environment within the cab, NIOSH discovered that filtration efficiency was critically important. Removal of particles between 0.3 and 10 microns, medically determined to be the human respiratory range, became the target for filter efficiency.

NIOSH partnered with Sy-Klone International in Jacksonville, Florida, for a series of research studies focused on filtration efficacy on "in-use" drilling cabs. The findings showed that the engine filter media used in the cab filtration was inadequate to address particles in the human respiratory range of 0.3 to 10 microns. NIOSH then tested the cab with a newly developed technology comprised of a high-efficiency powered pre-cleaner paired to a robust, patented high-efficiency filter. This new technology, known as RESPA®, proved highly effective at removing respirable particles on first pass through the filter. With this solution, there was still a need for a test method capable of rating high-efficiency filtration. The AHSRAE 52.2 test standard satisfied this requirement. At that time, there were no filter test standards that had, as their focus, low-airflow, high-efficiency filtration for use in heavy equipment.

NIOSH sent OSHA the results which demonstrated that it was not only possible, but practical, to comply with the filtration requirements of the OSHA Silica Regulation.

Let us return for a moment to the MERV rating system offered by ASHRAE under its 52.2 test standard. The efficiency rating scheme ranges from extremely low-efficiency filters all the way to the highest-efficiency filters. The ratings, as initially adopted in the standard, went from MERV 1 to MERV 20. MERV ratings above 16 were commonly known as HEPA (High Efficiency Particulate Air) filters. These HEPA ratings, MERV 17-20, have since been removed from the rating system offered by ASHRAE. See Figure 2.

HEPA filtration, developed during the Manhattan project to protect lab workers from inhaling radioactive isotopes, has remained the highest level of particulate filtration. Traditionally, HEPA filters are made from glass fibers randomly layered on top of one another to form a

MERV RATING CHART

Standard 52.5 Minimum Efficiency Reporting Value	Dust Spot Efficiency	Arrestance	Typical Controlled Contaminant	Typical Applications and Limitations	Typical Air Filter/Cleaner Type
20	n/a	n/a	< 0.30 pm particle size	Cleanrooms	≥99.999% eff. On .10-.20 pm Particles
19	n/a	n/a	Virus (unattached)	Radioactive Materials	Particles
18	n/a	n/a	Carbon Dust	Pharmaceutical Man.	Particulates
17	n/a	n/a	All Combustion smoke	Carcinogenetic Materials	>99.97% eff. On .30 pm Particles
16	n/a	n/a	.30-1.0 pm Particle Size	General Surgery	**Bag Filter**- Nonsupported microfine fiberglass or synthetic media, 12-36 in. deep, 6-12 pockets
15	>95%	n/a	All Bacteria	Hospital Inpatient Care	
14	90-95%	>98%	Most Tobacco Smoke	Smoking Lounges	
13	89-90%	>98%	Droplet Nuceli (Sneeze)	Superior Commercial Buildings	**Box Filter**- Rigid Style Cartridge Filters 6 to 12" deep may use lofted or paper media.
12	70-75%	>95%	1.0-3.0 pm Particle Size Legionella	Superior Residential	**Bag Filter**- Nonsupported microfine fiberglass or synthetic media, 12-36 in. deep, 6-12 pockets
11	60-65%	>95%	Humidifier Dust Lead Dust	Better Commercial Buildings	
10	50-55%	>95%	Milled Flour Auto Emissions	Hospital Laboratories	**Box Filter**- Rigid Style Cartridge Filters 6 to 12" deep may use lofted or paper media.
9	40-45%	>90%	Welding Fumes		
8	30-35%	>90%	3.0-10.0 pm Particle Size Mold Spores	Commercial Buildings	**Pleated Filters**- Disposable, extended surface area, thick with cotton-polyester blend media, cardboard frame
7	25-30%	>90%	Hair Spray	Better Residential	**Cartridge Filters**- Graded density viscous coated cube or pocket filters, synthetic media
6	<20%	85-90%	Fabric Protector Dusting Aids	Industrial Workplace	**Throwaway**- Disposable synthetic panel filter.
5	<20%	80-85%	Cement Dust Pudding Mix	Paint Booth Inlet	
4	<20%	75-80%	>10.0 pm Particle Size Pollen	Minimal Filtration	**Throwaway**- Disposable fiberglass or synthetic panel filter.
3	<20%	70-75%	Dust Mites Sanding Dust	Residential	**Washable**- Aluminum Mesh
2	<20%	65-70%	Spray Paint Dust		**Electrostatic**- Self charging woven panel filter.
1	<20%	<65%	Textile Fibers Carpet Fibers	Window A/C Units	

Figure 2: MERV rating chart.

bird's nest of fibers. While extremely effective in trapping very small particles, HEPA filters, when subjected to dust, load quickly and become more restrictive to air flow. Due to the inability of HEPA media to withstand the rigors of high dust load, machine vibration and moisture, a new type of filter media was needed. Subsequent testing by NIOSH on glass fiber HEPA media has further substantiated these observations.

How does the silica rule impact HVAC manufacturers?

Engineering controls listed in the Silica Regulation include high-efficiency filtration. If not properly engineered, adding restrictive filtration to the HVAC system can compromise HVAC efficiency. HVAC manufacturers should take this into consideration, to allow for the use of high-efficiency filtration.

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So, what does the Silica Regulation mean to anyone other than the machine owner?

Standards in any industry or technology are subject to change. Discoveries find their way into new devices in many ways. As it relates to those discoveries that impact human health directly, the path to device implementation is much quicker. History serves up an interesting example which helps to illustrate this point (Figure 3).

Volvo saw that it had the potential to save lives and intentionally did not patent the idea, hoping that it would be adopted by all car manufacturers. Then President of the United States Richard Nixon thought the three-point safety belt was a good idea and signed it into law as a requirement in 1974. The three-point safety belt became state-of-the-art for safety devices and is now included with every vehicle.

media.volvocars.com

Figure 3: In 1959 Nils Bohlin, a Volvo engineer, invented the three-point safety belt. It proved remarkable in its ability to prevent lower-lumbar separation in traffic accidents.

Market acceptance of a safety device

When a device or process is proven to positively impact safety, and it can be achieved at what is considered a reasonable cost, it becomes difficult to argue in favor of not including it. Under OSHA's new silica regulation, MERV 16 or better filtration is required for fresh air intake systems on cabs. Continuous pressurization, along with the other engineering controls, are also required by the Regulation.

Knowledge of these facts creates an interesting tension between legal requirements and the market's requirements. The two are not always the same or adopted simultaneously. However, legal arguments concerning state-of-the-art could go something like this: the manufacturer knew at the point of manufacture that the filter would not adequately protect the operator of the cab from respirable dust. Regardless of the operator's hygienic practices, the cab was not engineered to protect him.

Standards, regulations, and the future of HVAC design

In Europe, regulations are promulgated under the European Commission as European Norms, whereas in the USA they are promulgated by a standard writing organization such as SAE, ASHRAE, ASABE, and others. Eventually, some of these various standards are adopted by the American National Standards Institute (ANSI) as an American National Standard. Internationally, standards may be adopted under the International Organization for Standardization (known in the USA as ISO).

The need for a testing method for low-airflow, human-respiratory filters typical of heavy equipment HVAC systems is satisfied only in two standards, EN1822 and ISO 29463. All five sections of EN1822 were adopted as a European Norm in 2009. EN1822 addresses high-efficiency, human-respiratory filtration in the manufacture, testing, and rating of filters. In 2011 ISO adopted EN1822, with few changes, as ISO 29463. Reaffirmed in 2017, this ISO standard is the only one that addresses all the issues associated with the manufacture, testing, and rating of filters used in low-airflow operator environments. Additionally, the standard allows for radial style and panel style filters using all known filter media types. It is comprehensive and well written.

In the USA, ASHRAE is aggressively looking for an alternative to replace its 52.2 Standard. Alternatives for ASHRAE do not intersect with the needs of heavy equipment HVAC manufacturers. SAE is wrestling with what standard should replace the current ISO 5011 engine filter test when applied to human operating environments. While there may be a good deal of work yet to do, the organizations are developing standards that will result in improved air quality in operator cabs working in contaminated work environments.

ISO Technical Committee-82 has initiated a working group to develop a standard which addresses engineering controls, post-manufacture performance testing, and ongoing maintenance of mining machine cabs. This standard, which may be adopted for use on operator enclosures used in other industries like heavy equipment and agriculture, applies to both newly-manufactured cabs and existing cabs.

The future of the OSHA silica rule

OSHA recently announced that it will be issuing a call for information on ways that Table 1 of the silica rule can be improved. Issues with interpreting and enforcing Table 1 have accelerated the need to update the table. If you have suggestions on how to improve Table 1, please take advantage of this opportunity to share it with OSHA.

It is worth noting that the International Union of Operating Engineers, which has over 300,000 members nationwide, spoke in favor of the silica regulation's ability to better protect their operators. There is no evidence that the mass of testimony given during the public debate on the OSHA silica regulation will be countermanded. What remains is market adoption and widescale implementation of the engineering controls and testing regimen found in the OSHA silica regulation.

Tucker truck and machinery hits a cab-air quality grand slam

Recently I had the privilege of representing the International Society of Environmental Enclosure Engineers (ISEEE) at Tucker Truck and Machinery in Leesburg, Florida. Tucker and Visionaire Inc. (a Dallas-based HVAC manufacturer and longtime member of MACS) asked ISEEE to confirm the air quality performance of a newly-completed T-644 cab. The design objective was to maintain continuous cab pressurization and to keep particle concentrations within the cab below the 50 ug/m3 required by the OSHA silica rule (Figure 4).

The ISEEE in-field testing method involves testing the fresh and recirculation systems separately with a test aerosol producing particles in the human respiratory range. The T-644 cab air quality performance was outstanding. The average dust concentration in the cab was maintained at 2 µg/m3 while subjecting the fresh-air intake on the HVAC to

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Figure 4: This Tucker T-644 concrete transporter cab was designed and manufactured with state-of-the-art, best-practice recommendations from ISEEE.

over 200,000 µg/m3 of aerosolized particulate. This test demonstrated the effectiveness of Sy-Klone's RESPA-CF2 (Figure 5) with the MERV16 filter, which was responsible for pre-cleaning and filtering the air before it entered the HVAC mixing plenum. See Figure 6.

We then ran the aerosol generator inside the cab while the machine was running. The HVAC fan was on high, and the door was shut until the particle concentration rose to just over 521,000 µg/m3. The aerosol generator was then shut off. One minute later, with the cab door remaining closed, the average particle concentration dropped to just over 61,000 µg/m3. Two minutes later, the concentration had fallen to 9.9 µg/m3. After 3 minutes, the average dust concentration had fallen to 2.6 µg/m3. The air quality in the cab was practically free of dust within two minutes after being subjected to extreme dust conditions inside of the cab. This test demonstrated the effectiveness of Sy-Klone's RESPA-CFX2 with the MERV16 filter, which was responsible for filtering the recirculation air before it entered the HVAC mixing plenum.

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Figure 5: Vision Air HVAC and RESPA-CF2 with MERV 16 filter

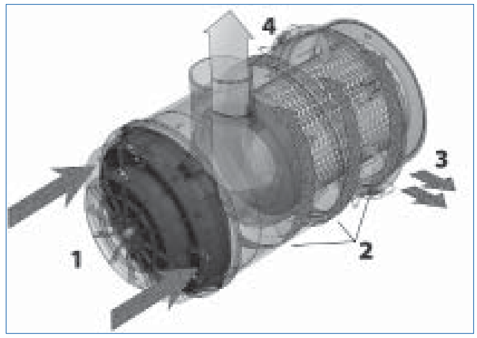

Figure 6: Diagram showing how RESPA works: 1) Particulate-laden air is pulled into the powered pre-cleaner; 2) Heavier-than-air particles travel along the outer walls in a vortex pattern; 3) Debris is forcefully ejected from the pre-cleaner; 4) Precleaned air is gently pushed through the filter media, providing only clean air to the HVAC unit.

This test demonstrated the effectiveness of the cab as a system to provide excellent air quality to the operator, HVAC system and cab electronics. The silica regulation limits silica exposure to 50 µg/m3. With a dust concentration of approximately 2.0 µg/m3, Tucker Truck and Visionaire have done what was previously thought impossible—designed a cab that complies with the silica rule, maintains continuous cab pressurization, is easily maintained, highly effective, and relatively inexpensive. The design, which was completed within several months, incorporates all recommended ISEEE best practices to ensure excellent air quality performance and low maintenance over the life of the cab. ❄

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Jeff Moredock is an Executive Vice President at Sy-Klone International, the international project lead for ISO 23875 (Mining—Operator enclosures—Air quality control systems and air quality performance testing), and president of the International Society of Environmental Enclosure Engineers. He also serves on a various SAE, ASABE, AEM, AIHA, and ISO committees and work groups. Jeff is the author of the Advanced Cab Theory Workbook, and is an Advanced Cab Theory course instructor. Jeff presented at the MACS conference in 2011, and has been a guest speaker at mining, industrial hygiene, and other trade association conferences and events.