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Respirable crystalline silica is a confirmed occupational exposure risk during hydraulic fracturing: What do we know about controls? Proceedings from the Silica in the Oilfield Conference

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Introduction

Risks for occupational exposures to respirable crystalline silica (RCS) during hydraulic fracturing were first systematically evaluated and reported by researchers at the National Institute for Occupational Safety and Health (NIOSH) in 2013.[1] At the time, NIOSH researchers determined that RCS exposures during these operations exceeded the relevant occupational exposure limits, in some cases by a factor of 10 or more. Health effects from RCS exposures can include silicosis, lung cancer, kidney and skin diseases, depending on the magnitude and duration of exposure.[2] In response to these findings, NIOSH researchers developed recommendations for hydraulic fracturing companies to implement controls for the seven primary point sources of aerosolized RCS identified during their research.

1. Dust ejected from thief hatches on the tops of sand movers during filling.
2. Dust released from the sand mover conveyance belt.
3. Dust created from the momentum of proppant falling into the blender hopper.
4. Dust released from transfer belts when proppant is deposited onto the belt and conveyed to the blender.

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5. Dust generated as proppant leaves the end of the transfer belt (i.e., "the dragon tail".)
6. Dust ejected from fill ports on the sides of sand movers during refilling operations.
7. Dust generated by wellsite traffic.

Since the 2013 paper was published, a variety of controls have been developed and incorporated into equipment and work practices to address the exposure risk. Despite this, many questions are asked, both within and outside of the industry, about their effectiveness for protecting all workers potentially exposed. Answers to these questions are even more important in light of the Occupational Safety and Health Administration's (OSHA's) final rule on Occupational Exposure to Respirable Crystalline Silica, published March 25, 2016. In addition to establishing a new 8-hr, time-weighted average (TWA) permissible exposure limit (PEL) of 50 micrograms per cubic meter ($\mu g/m^3$) and an action level of 25 $\mu g/m^3$, for all silica polymorphs, the standard requires implementation of engineering controls during hydraulic fracturing by June 23, 2021.[3]

On March 21, 2018, the American Industrial Hygiene Association's (AIHA®) Rocky Mountain Section and the American Society of Safety Professionals' Colorado Chapter convened Silica in the Oilfield, a day-long conference for health and safety professionals working in oil and gas exploration and production. For the conference, a number of oil and gas extraction industry representatives were invited to present on currently available controls designed to limit occupational exposures to RCS from quartz sand proppant during hydraulic fracturing operations. The Silica in the Oilfield conference allowed industry presenters the opportunity to explain and discuss their development and implementation of controls including elimination of quartz sand, substitution of alternative (non-quartz) proppants, alternative ways to transport and handle quartz sand, policy and procedures and training, and lastly, use of respiratory protection.

This commentary includes summaries of the conference presentations describing controls developed to help minimize RCS exposures from quartz-containing sand proppant during hydraulic fracturing. Summaries of the presentations are grouped into control types including:

- elimination: use of alternative, non-quartz containing proppant;
- substitution: use of treated quartz sand to minimize RCS aerosol emissions; and
- engineering controls: minimizing aerosol generation at proppant transfer/aerosol generation points, aerosol containment through alternative handing and transport methods, and vacuum collection at the point of generation.

No presentations centered solely on administrative controls (e.g., minimizing numbers of workers in high risk areas, worker training, development of policy and procedures) nor promoted respirators as a sole means of control. However, administrative controls and personal protective equipment (PPE) were described as continuing to be applied in addition to elimination, substitution and engineering control measures implemented for workers where risks for RCS exposures still exist. Respirators would be used until such time when enough data conclusively demonstrates the effectiveness of controls to negate the need for respirator use for all at-risk workers.

While this commentary will inform readers on some types of available controls to minimize RCS exposures during hydraulic fracturing, they do not represent the entirety of available controls or control manufacturers. It is important to note that while the conference focused on controlling silica exposures the technologies presented have operational advantages that may further aid health and safety professionals in making a business case for implementation of controls. In this article, we also present commentary on:

- the limitations of the data presented;
- the paucity of and need for well-designed studies evaluating the effectiveness of controls as reported in the scientific literature; and
- the need for companies to perform due diligence to ensure that any controls implemented are properly evaluated to ensure effectiveness in reducing or eliminating occupational RCS exposures.

Silica in the Oilfield Conference Proceedings

Category: Elimination using non-RCS proppant

CARBO Ceramics Inc. (Houston, TX) developed and reported on an engineered ceramic proppant as a replacement for quartz sand. Because of its design and material components, ceramic proppant can serve to eliminate the risk of silica aerosolization and exposure as compared to quartz sand proppant. Ceramic proppant is a sintered pellet of uniform dimensions that is harder than quartz, allows greater conductivity (i.e., ability to allow oil and gas to flow through the proppant pack), and is compatible with hydraulic fracturing chemistry and wellbore conditions.

Kaolin clay and bauxite (an aluminum-bearing ore) are the most common materials used in ceramic proppants. While kaolin clay contains crystalline silica, sintering incorporates the silica into the proppant matrix, minimizing or eliminating silica emissions. Ceramic proppant was reported by the presenter to be non-bio accumulative, non-hazardous, and non-toxic based on requirements for the European North Sea markets. Compared with quartz sand, ceramic proppant was reported to require less proppant and water use, reduced wear on hydraulic pumps, and less overall time for similar hydraulic fracturing operations on a given well.

CARBO reported that air monitoring for RCS was conducted at its manufacturing plants during proppant handling operations chosen to replicate processes and equipment used by customers during handling, conveying, screening, transfer, and packaging. Personal breathing zone (PBZ) and area samples were collected to assess 8-hr exposures to RCS over a 2-year period at multiple plant locations. Samples were reported to be analyzed by AIHA-accredited laboratories.

Results from PBZ and area samples collected at CARBO facilities (as quartz, cristobalite, and tridymite) were reportedly below minimum detectible concentrations for RCS as

TWAs. CARBO reported their assessments demonstrate that under the conditions of their evaluations, mechanical handling of sintered lightweight ceramic proppant does not generate RCS concentrations greater than the current OSHA action level.

Category: Substitution using treated sand

Covia Corp. (Independence, OH; formerly Unimin) developed a chemical (resin) treatment for quartz sand to reduce RCS aerosol emissions, creating a less-hazardous treated product that can be substituted for more-hazardous non-treated quartz sand proppant. Laboratory and field evaluations were conducted to evaluate various treatments. In one unpublished evaluation, 6,000 lbs of 40/70 mesh treated and non-treated quartz sand was transported from a sand silo onto a transfer belt and then pneumatically transferred into an open top container (i.e., a commercial dumpster) simulating pneumatic transfer into a sand mover bin as the sand impacted against the dumpster floor and walls. Five area air sampling trains were positioned in and around the dumpster. Results comparing treated vs. non-treated quartz sand reportedly resulted in total dust reductions in a range of 87–98%. Treated sand samples were reportedly evaluated multiple times simulating truck movements, silo storage, and loading operations; no loss of treatment effectiveness was reported after six months of storage.

In another unpublished evaluation, Dorr-Oliver size-selective cyclones and real-time aerosol sampling instruments were used to collect and record area air samples near quartz sand conveyance/transfer points. When untreated sand was conveyed, real-time instrumentation reportedly recorded aerosol concentrations up to 400 mg/m^3. Using treated sand, respirable aerosols were reportedly reduced 97–99% compared to untreated sand.

A third unpublished evaluation reportedly involved collection of 32 PBZ samples during 12-hr shifts while hydraulic fracturing and sand transport operations were occurring. Sixteen samples each were collected to compare treated vs. untreated sand. The PBZ samples for RCS from untreated sand exceeded the previous OSHA calculated PEL criteria (based on percent silica in the sample), some by a factor of 10 as a TWA. Use of treated sand reportedly resulted in 88% of the PBZ samples being less than the current OSHA action level. Two PBZ measurements exceeding the new PEL of 50 μg/m^3 as a TWA were reported to be associated with a broken transfer belt that required operators to shovel sand to access and repair the belt. Most measurements were reported to be at or below the current OSHA action limit of 25 μg/m^3 as a TWA, suggesting that substitution using treated sand is a viable control. However, it was emphasized that overexposures to RCS can occur during maintenance work or when improper work practices such as dry sweeping occurs.

Category: Engineering controls I, using non-pneumatic transfer systems

PropX (Denver, CO) is a brand name for a non-pneumatic proppant containment and delivery technology intended to reduce RCS emissions and enhance operational efficiency related to proppant delivery and transport. Quartz sand is delivered to the wellsite in stackable, modular bins that are stored on-site. The bins are moved into place adjacent to the blender truck, and sand is gravity-fed from bins to an enclosed transport belt for delivery into the blender hopper. Additional proprietary controls are used around the blender hopper.

Distance from the sand holding/containment bin to the transport belt is minimized to prevent aerosols from being generated during proppant delivery.

The PropX technology involves both engineering and administrative controls to reduce RCS emissions. Non-pneumatic transfer is intended to reduce quartz sand disintegration and subsequent RCS aerosol generation. Sand disintegration resulting from frictional forces during the pneumatic transfer of sand during sand delivery had been identified by NIOSH. Proppant stored on-site was reported to reduce the numbers of sand truck deliveries and potential for RCS re-aerosolization created by truck traffic during hydraulic fracturing operations. The ability to operate the technology remotely helps minimize the time sand truck delivery drivers spend outside their cab while on site. PropX reported to have achieved best-in-class RCS dust reduction based on evaluations performed by third-party industrial hygiene consultants using an AIHA-accredited laboratory for sample analyses.

Category: Engineering controls II, using non-pneumatic transfer systems

The Calfrac Well Services Ltd. (Calgary, Alberta) approach to transfer and handling of quartz sand involves recognition that variables including wind velocity and direction, humidity, and types of quartz sand being handled are not controllable. However, how controls are developed, designed, implemented and incorporated into process operations during transport and handling of quartz sand proppant can be managed, controlled and confirmed.

The system developed and used by Calfrac helps to eliminate RCS emissions created during pneumatic transfer operations from bulk sand delivery trucks into sand moving machinery (e.g., Sand Movers, Sand Chiefs, Sand Kings). Instead of pneumatically transferring sand from delivery trucks, Calfrac’s system offloads sand from delivery trucks through a belly dump onto a conveyor belt that gradually fills vertically oriented bins. Sand from the bins is then unloaded onto an enclosed horizontal conveyor system that directly feeds into the blender hopper. Except for final discharge to the blender hopper, almost all sand conveyance is enclosed, largely eliminating RCS aerosol emissions into the occupational environment. Aerosols generated when the sand is conveyed into the blender hopper can be controlled with additional engineering controls such as enclosures, tenting, or vacuum extraction systems.

Results of extensive area and PBZ air monitoring were reportedly used to develop worker exclusion zones typically located around the conveyor belt offloading zone for the sand trucks and around the blender hopper. While occupational exposures for RCS for personnel working in these areas may be less than the current OSHA PEL of 50 $\mu g/m^3$ as a TWA, Calfrac still requires use of air-purifying half-face respirators in the exclusion zone(s).

Administrative controls are also in place including development/implementation of a silica exposure control plan and continued exposure assessment protocols, policy and procedures for worker training, annual pulmonary function testing, respirator fit testing, and a medical surveillance program for all potentially exposed personnel. Calfrac also conducts regular air monitoring using in-house industrial hygiene staff.

Category: Engineering controls III, using non-pneumatic transfer systems

Arrows Up LLC (Denver, CO) has developed a containerized, gravity-driven sand transfer system designed to minimize mechanical handling of quartz sand that can lead to generation of RCS aerosols. The system incorporates a “riser” holding three sand bins (capacity range 43,000–50,000 lb) positioned directly over the hopper of the blender truck. Each bin is controlled with a gate valve allowing sand to be gravity-fed to a chute leading into the hopper of the blender truck. Sand is not conveyed on belts or with pneumatic transfer. As a bin is emptied, the adjacent bin is brought into service to supply sand. Empty bins are removed and replaced using a forklift and loaded onto a flatbed transport for sand refilling at a rail/truck trans-load facility or a sand terminal. Full and empty bins can be stacked and stored on site. Three fully loaded bins reportedly provide enough proppant to minimize running short on sand during hydraulic fracturing operations.

Arrows Up reported evaluating their technology in multiple geographically diverse areas including the Permian, Haynesville, Eagle Ford, Mid-continent, and Marcellus basins under representative hydraulic fracturing conditions. In an unpublished evaluation, 18 PBZ and seven area samples were collected for RCS aerosols. The arithmetic means for both the PBZ and area samples were reported to be less than the current OSHA action level for the 12-hr shifts evaluated. Additional exposure monitoring was reportedly being conducted bi-annually in accordance with new OSHA Silica Standard. Reportedly, there was one situation where the OSHA action limit for PBZ samples was exceeded: during clean-up (e.g., shoveling/sweeping) of spilled sand and respiratory protection was required during that task.

Category: Engineering controls IV, using a vacuum system

Airis Wellsite Services LLC (The Woodlands, TX) designs and uses vacuum collection systems to collect RCS emissions from thief hatches on sand movers and other sand containment devices. The system includes a 45,000 ft^3 per min vacuum, ductwork, and manifold system elevated above the working surfaces to prevent tripping hazards and keep equipment out of the way of workers. Ductwork connects the vacuum unit to sand mover thief hatches with patented hoods to collect RCS emissions. The system can be configured for other sand delivery and transfer options such as sand silos and sand boxes. Shrouding is placed around transfer belts and the blender hopper to contain RCS emissions. The vacuum collection system reportedly includes 60 filters that are air-purged every 10 sec. A screw augur transports the collected RCS dust to a Super Sack™ for containment and disposal. Connections for up to six sand movers can be configured with the system.

Using data from their field studies, Airis developed an air sampling database containing approximately 400 samples. Results from air sampling conducted around sand movers without controls were described as being similar to the results published by NIOSH in 2013.[1] Approximately 70% of the samples were described as exceeding the new OSHA PEL, approximately 10% were below the new PEL and 20% were below the new action level. Airis stated their system can control RCS emissions so that approximately 75% of air samples collected will be less than the new action level, but full compliance with the new OSHA silica standard is challenging. Airis reported that in an unpublished evaluation conducted in 2016, approximately 4% of air samples collected were determined to be in excess of the new PEL; the cause was attributed to worker destruction of a containment/ shrouding system that apparently interfered with workers' ability to see certain work operations. Reportedly, the shrouding system was modified and the customer revised work practices to resolve the problem.

The next steps

Six years have passed since exposure risks for RCS during hydraulic fracturing were first published by NIOSH.[1] In that time, a variety of elimination, substitution, engineering, and administrative controls have been conceived, developed, and implemented to help limit worker exposures to RCS during hydraulic fracturing operations. The use of air-purifying respirators is no longer a sole control option. The conference proceedings described in this commentary are notable and an important contribution to the discussion surrounding what we know about silica controls in this industry. However, limitations to the information presented at the conference exist and are acknowledged. These include lack of more exhaustive detail related to industrial hygiene sampling data and results as well as the lack of third-party confirmation and public reporting of the control assessments. Little in the way of scientific publications discussing new controls and describing evaluations of new controls has been made available. In 2018, a trade journal article, "Tools Minimize Silica Dust Exposures", was published in *The American Oil and Gas Reporter*.[4] NIOSH published two articles in the *Journal of Occupational and Environmental Hygiene* in 2016 and 2018 evaluating the effectiveness of a mini-baghouse retrofit assembly that NIOSH invented for use with pneumatic transfer of sand into sand moving machinery.[5,6] Additional rigorous research in the area of the effectiveness of controls is needed to inform and educate oil and gas management and industrial hygiene/health and safety professionals in making decisions and selections about controls. Companies planning to purchase or contract commercially developed controls need to understand the effectiveness of new controls, especially engineering controls. Manuscripts describing the materials, methods, and conclusions of control evaluations are particularly needed for companies planning to purchase, contract, or implement controls.

Confirming the effectiveness of controls especially under the dynamic workplace conditions of hydraulic fracturing, where numerous point source emissions are present, is a challenging undertaking requiring industrial hygiene/safety, engineering and managerial expertise. A systematic and well-conceived approach and strategy to evaluating control effectiveness is required; a "one and done" assessment is likely insufficient. Confirming that controls are effective will likely require iterative efforts as process operations, proppant use, work practices, and equipment and site configurations change. Based on the hierarchy of controls, reliance on air-purifying respirators (the simplest, but least preferred control strategy) is not recommended. Rather, a basket of goods approach involving all aspects of the hierarchy of controls will likely be required considering the seriousness of potential occupational health consequences that are possible from overexposures to RCS and the fact that multiple point source emissions need to be addressed.[1]

Conclusion

While remaining attentive to the “soon and certain” safety aspects (i.e., prevention of serious injuries and fatalities) during oil and gas extraction, the imperative is also that we focus as intently on controls to mitigate the risks for “long and latent” adverse health outcomes, in this case preventable but extremely serious lung disease, including lung cancer. We can do this by understanding if we effectively control occupational exposures today, we have prevented occupational diseases decades away.

As part of the NIOSH Oil and Gas Extraction Program, NIOSH is actively soliciting that companies involved in oil and gas extraction form partnerships with NIOSH to evaluate the effectiveness of exposure controls used during oil and gas extraction in general and hydraulic fracturing specifically.[7] NIOSH is currently engaged in the first year of a four-year project entitled “Controls and Interventions for Hazardous Exposures in Oil and Gas Extraction.” The intent is to generate objective data evaluating the effectiveness of controls for silica exposures in this industry in cooperation with industry partners, where data quality meet the expectations of peer-reviewed scientific journals to advance the knowledge of worker health protection, through effective use of controls in hydraulic fracturing operations.

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