Introduction

Hydraulic fracturing is a technique used to increase well production rates which was first used in the 1940s. After a well is drilled, the well bore is subjected to high pressures using a mixture of water and chemicals which are injected into the well. This causes many small fractures in the formation which release oil or natural gas from the formation. To prevent the fractures from closing under the confining pressure of deeply buried formations, a proppant such as fine mesh sand or ceramic material is mixed into the fracturing fluid. When the rock fractures, the rush of water into the newly-opened pore space carries sand grains deep into the rock unit. When the water pressure is reduced the sand grains "prop" the fracture open and allow a flow of natural gas or oil through the fractures and into the well bore. This is the prop sequence stage. It may consist of several substages where the well casing is perforated in a small section of the well bore before the fracturing fluids and proppant are injected to fracture the formation around that portion of the well bore. This process may collectively use several hundred thousand gallons of water and hundreds of thousands pounds of sand. Proppant material may vary from a finer particle size to a coarser particle size throughout this sequence and other treatments such as acid injection may be used to facilitate the fracturing. The stimulation technique has successfully increased well production rates and the practice has spread. It is now used throughout the world in thousands of wells every year.

The proppant material, typically natural sand, contains high levels of crystalline silica. This is a desirable trait in the proppant as the crystalline structure provides the strength to hold the fractures open while allowing liquids to flow out of the formation. However, exposure to respirable crystalline silica particles, which are small enough to enter the gas exchange regions of the lung, has been identified as a long term occupational health hazard (OSHA 2012). Cumulative exposure to crystalline silica particles of respirable size may cause an increased risk of silicosis, lung cancer, emphysema, chronic bronchitis, and pulmonary function impairment (NIOSH 2002) (OSHA 2010). Mechanical handling of the large volumes of dry sand required during the fracturing process can cause worker exposure to respirable crystalline silica.

Silicosis usually develops after long term exposure (10 to 20 years) to low levels of silica dust but can be accelerated by high exposures of only a few months to a few years (NIOSH 2002) (Banks 1986) (Peters 1986). In the early stages of the disease, the patient suffers from shortness
of breath, chronic cough, and fever. Patients in the late stages of silicosis often experience severe shortness of breath, chest pain, fatigue, weight loss, and respiratory failure which can cause death. Silicosis is not curable. The disease is treated through medication and treatment with oxygen.

**Why All the Recent Attention to Silica Exposures in Hydraulic Fracturing**

Despite the age of the technology, hydraulic fracturing has been out of the public eye until recent years. Technological improvements to the process have led to a boom in well stimulation contributing a $284 billion increase in the US Gross Domestic Product (GDP) in 2012 (IHS 2013) and creating a new industry employing approximately 200,000 people in 2013 (BLS 2014). The increased use of this technology has resulted in a corresponding increase in efforts to improve worker safety. These efforts include the National Institute for Occupational Safety and Health (NIOSH) Field Effort to Assess Chemical Exposure Risks to Gas and Oil Workers, the

Occupational Safety and Health Administration (OSHA) proposed rule addressing occupational exposure to respirable silica, and efforts by industry groups such as the Silica Focus Group of the National Service, Transmission, Exploration & Production Safety (nSTEPS) Network and the American Petroleum Institute to characterize worker exposures and disseminate information on best practices.

**Risk Evaluation and Industrial Hygiene Monitoring**

The potential for exposure to respirable crystalline silica is present wherever handling of dry sand occurs and a primary method to characterize the exposure and assess the risk is through air monitoring of worker exposures. Measuring worker exposures is necessary to make informed decisions about the controls necessary to protect workers from respirable crystalline silica. It may be apparent from visible dust clouds that respiratory protection is necessary to protect workers until other control(s) can be implemented. However, the level of protection necessary may not be readily apparent. Most of the respiratory protection currently in use during hydraulic fracturing operations is half face respirators. Yet some results collected by NIOSH exceeded the OSHA calculated PEL by more than the half face respirator’s assigned protection factor (Esswein 2013). In these cases, full face or better respiratory protection is required to provide adequate protection. Industrial hygiene measurements provide the information necessary to define areas for controls and to determine respiratory protection requirements. Additionally, a solid baseline of industrial hygiene data can be used to guide other control decisions and evaluate control effectiveness.

Additionally, monitoring records can serve to establish compliance with health and safety regulations. Even if exposure measurements are above established limits, they can be used to demonstrate that the correct level of respiratory protection was provided to workers.

**Planning the Survey**

Before beginning an air monitoring campaign, some planning is necessary to ensure efficient use of time and money. Begin by establishing a team of professionals including experienced industrial hygienists (IH). A Certified Industrial Hygienist (CIH) will bring experience in the industrial hygiene process necessary for planning as well as execution and oversight of sampling
activities. Oilfield experience is a plus for the IH team as the pace, variability, and remote location of upstream activities can prove challenging. The sample analysis is as important as the field work. To ensure accurate, reliable data, all samples should be analyzed by a laboratory accredited by the American Industrial Hygiene Association (AIHA). Establishing a relationship with a laboratory ahead of time may prove beneficial as their experienced personnel can provide guidance on many aspects of sampling.

The first task of the IH team should be to define the purpose and goals of the sampling campaign. This will guide the selection of sampling methods as well as the type and number of samples to collect. Worker exposure is best assessed through personal breathing zone samples while control evaluation may require area samples and source isolation. The team should also know which standards and guidelines they will use to evaluate sample results as well as whether those limits will be adjusted to handle work shifts greater than eight hours which are common in upstream operations. The OSHA PEL is enforceable but exposure limits from NIOSH or the American Conference of Governmental Industrial Hygienists (ACGIH) may be more protective of workers.

**Similar Exposure Groups**

When evaluating worker exposures, it is common practice to divide workers into similar exposure groups (SEG) which is a group of workers performing similar activities resulting in similar potential exposures. Although many job positions at a well site are staffed by one individual, these jobs may be grouped according to their potential for silica exposure. In Appendix A of the Preliminary Economic Analysis for the proposed silica rule, OSHA breaks workers down into three groups: Fracturing Sand Workers in the Central Area, Ancillary Support Workers, and Remote/Intermittent Support Workers. While the first group is directly involved in the sand moving process such as sand mover and blender operators, the second group is located on the periphery of the sand moving area. This includes workers operating chemical additive and hydration units. While not directly involved in moving sand, their proximity increases their potential for exposure. The last group, remote/intermittent, includes workers such as wireline crews whose location on the well site places them some distance from the sand moving operations. Their potential for exposure is much lower than the first two groups. Inclusion in these groups must be tailored to local practices and well site layout and the remote/intermittent group may need to be split into two groups to differentiate between workers whose jobs may require entry into the sand moving area (maintenance mechanics) from workers whose jobs do not (wireline). Deciding how to group employees is where an experienced IH team can prove valuable.

**Contract Workforce**

Another challenge to upstream IH work is deciding how to handle the many contract workers on site. In hydraulic fracturing, much of the work is conducted by well site services contractors. Many of these may be small companies with few if any safety support staff. Owners must decide if they will provide IH monitoring services or if it will be left up to the contractor to monitor their employees. This can be specified in contractual language but enforcement can be a challenge. If the owner or operator elects to include a contract worker in the IH monitoring survey, that employee must be allowed access to the exposure record or notified of the results of the exposure monitoring.
Factors Affecting Results

The importance of field observations and detailed, accurate notes during an IH monitoring survey cannot be overstated. This is especially true in the case of silica monitoring during hydraulic fracturing. There are many variables that may affect the measured levels of respirable silica including worksite layout, weather conditions such as wind speed and direction, rain or fog, proppant type, and mesh size. Process variables such as flow rates and proppant concentration affect the speed with which proppant must be delivered to the blender which can increase the level of visible dust. The volume of proppant required for each stage will affect the number of sand delivery trucks which must be unloaded. The source of the proppant may also affect exposure levels. “Clean” sand produces less visible dust than “dirty” sand. Different types of sand moving equipment and how that equipment is used may produce more or less dust. High levels of traffic can increase dust levels by stirring up local soil or spilled proppant.

All of this information can be important when interpreting the results of a silica monitoring campaign. Reviewing this information with the IH team and creating field data sheets to capture pertinent information can help ensure the necessary detail is available when interpreting the monitoring results.

Sampling Methodology

Sampling for respirable crystalline silica involves separating the respirable fraction, defined as a cut point of less than four microns aerodynamic diameter, from the larger dust particles. There are several pieces of equipment available to accomplish this task. Established sampling methods published by OSHA and NIOSH specify the use of a cyclone to separate the respirable particles which are then collected on a PVC filter for analysis. Cyclones rely on flow rate to determine the cut point. Accurately setting the flow rate is crucial as a flow rate that is set too low will capture larger particles and skew the results high where a flow rate that is too high will miss some of the respirable particles, biasing the results low. This makes it important to calibrate in similar conditions to the sampling conditions. If there is a dramatic change in temperature or elevation, the flow rate will be incorrect.

There is some debate in the industry over sampling methods; specifically the type of sampler to use. The OSHA method (ID 142) specifies the use of a 10mm Dorr-Oliver Nylon Cyclone while the NIOSH Method 7500 allows the use of two other cyclones. Recently developed size selective samplers have some advantages over the cyclone models specified in the two methods. Most notable is the ability to sample at higher flow rates. This is important to increase the sensitivity of the sample but care must be taken not to overload the filter in dusty environments.

The debate stems from the model specific language in the sampling methods. Concerns include validity of data sampled without using the cyclone specified by an established method.

Reporting

Finally, the IH team must know how to handle the data. Will they need to generate a report and what level of analysis is required? Employees must be allowed access to the exposure records in
accordance with 29 CFR 1910.1020 but who may have access outside of the affected employees.
If the company wishes to keep the data confidential, collecting it under attorney-client privilege
may provide some protection. However, it may also restrict future use of the data.

**Controlling Exposures**

The accepted hierarchy of controls considers respirators and other personal protective equipment
(PPE) as a last line of defense then other controls are inadequate. Respirators present many
challenges for the employer and the worker. For the worker, respirators add stress, especially in a
hot environment, and interfere with communication, hand signals can help. For the employer,
there is the cost of administering a respiratory protection program as well as the challenge of
ensuring workers are wearing their respirators correctly each time they put them on. Powered air
purifying respirators (PAPR) may help alleviate some of the burden on the worker but they still
require a respiratory protection program.

The decision to place employees in respiratory protection may have to be made in the
absence of exposure monitoring data. However, exposure monitoring should be conducted as
soon as possible to ensure the respirators are adequate. The NIOSH study found 9% of exposure
measurements exceeded 10 times the OSHA PEL, meaning a half face respirator would be
insufficient in these cases.

Implementing some administrative and work practice controls such as reducing spills and
the associated manual clean-up may reduce exposures and augment the effectiveness of
respiratory protection.

Engineering, Substitution, and other process controls are the best option. They take time
and money to develop, implement, and test but the costs of respiratory protection, potential
workers compensation cases, and liability can be saved. Source controls which have been
included at the design phase of the equipment are typically more effective than controls retrofitted
to existing equipment (Gambatese 2013). Start at the source: Containing the dust or substituting
with a non-silica proppant is best but isolating the receiver may be a viable option.

Commercially available equipment incorporating elements of engineering control is
currently being developed. Some products have been brought to market. However, these controls
must be evaluated to ensure the effectively reduce potential exposures and are applicable to
operational requirements.

A best practice is to start with a systematic, written exposure control plan which lays out
the plan for reducing excessive worker exposure to below permissible levels of crystalline silica,
including management and worker responsibilities, respiratory protection requirements, training
requirements, and the work practices may be used to reduce exposures. The Quick Fix
Suggestions pamphlet published by the National STEPS Network Silica Focus Group provides a
checklist of control actions. It is intended as a starting point and is not comprehensive (National
STEPS 2013).

It is important not to focus on silica exposures to the exclusion of other potential health
risks. Noise, carbon monoxide, diesel particulate and formaldehyde from diesel exhaust, naturally
occurring radioactive material, the chemicals used in hydraulic fracturing, weather extremes, and
biological hazards such as insects and animals may all present health risks at a hydraulic fracturing site.

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