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Learnings from the USA Energy Revolution on Workers' Exposures during Hydraulic Fracturing & Well Stimulation

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Background

The United States of America (USA) energy revolution has created a need to anticipate, recognize, evaluate and control worker exposures to chemical and physical hazards during well site development. The oil and gas industry is learning from the experience of managing occupational exposure risks of the past decades, such as asbestos and polychlorinated biphenyls to ensure that the development of environmental, health, and safety (EHS) risk assessment and management keeps pace with technological development. While exposures to chemical hazards typically associated with the oil and gas exploration, such as total hydrocarbons, are well understood and controlled, exposures to hazards that are new to hydraulic fracturing and well stimulation, such as crystalline silica, require assessment so the appropriate controls can be identified or designed and implemented. The USA oil and gas industry is matching the pace of technological innovations by including EHS considerations into this new technology. An overview of the methods used to assess exposure risks, the outcomes of the assessments, and successful control approaches are discussed.

Aim

The principle aim is to share Bureau Veritas North American's (BVNA) learnings about minimizing the potential for adverse health effects in workers during hydraulic fracturing and well stimulation worker through exposure risk assessment and control.

Occupational exposure risks to workers during hydraulic fracturing and well stimulation can be categorized into three categories, based on our understanding of the health hazards and the potential for adverse health effects from exposure.

The first category includes anticipated exposure risks, based on our knowledge from prior exposure assessments, which are associated with chemical, physical, and thermal hazards. Occupational exposure limits (OELs), sampling, and analytical methods have been established for well-understood chemical hazards, such as benzene, toluene, ethylbenzene, and xylenes (BTEX) along with total hydrocarbons. These OELs and methods support our ability to assess the potential for exposures to workers within the various job classifications during hydraulic fracturing and well stimulation and to verify that exposure control has been achieved. More importantly, they support our ability to anticipate potential risks and either eliminate or substitute the chemical hazard or include the appropriate exposure controls into the design of the work equipment and methods. The environmental learnings of hydraulic fracturing stimulation fluids in coalbed methane production wells are now applied to tight sands gas and shale gas production wells. BTEX-containing petroleum products were used as additives in stimulation fluids to improve the efficiency of the hydraulic fracturing process to reduce the water use. BTEX as an additive to hydraulic fracturing fluids was voluntarily discontinued in the USA in 2003 (USEPA 2004[i]) when alternatives were identified to avoid adverse impact to drinking water. This alternative substitution also reduces potential exposure risks to workers. However, in most geographic plays in the USA, liquid hydrocarbons, BTEX, and hydrogen sulfide, along with water, accompany the raw natural gas that it is extracted from the well. Therefore, the risk assessment process must also factor these potential exposures. The assessment and control of physical hazards, such as noise, are also well understood. Although exposure controls to mitigate the risk of noise-induced hearing loss are also most effective when included in the design of equipment and work methods, noise during hydraulic fracturing cannot currently be reduced to below commonly accepted exposure limits prompting the need for hearing conservation programs and ear plugs or ear muffs. Thermal hazards on hydraulic fracturing sites can range from excessive heat and sun exposure during summer months to extreme cold in winter. Learnings from other occupations, including construction, can be applied to control the potential impact to worker health and productivity from thermal hazards.

The second category includes occupational exposures to well-characterized hazards to which the risk to workers on hydraulic fracturing sites is uncertain. These include chemical hazards such as crystalline silica and diesel particulate and physical hazards such as vibration and naturally-occurring radioactive materials (NORM). It also includes uncertainty about the impact associated with the dermal routes of exposures to chemical hazards. The exposure risk to silica during hydraulic fracturing is an excellent example of the uncertainty of exposure risks to this well-characterized hazard. Since both the environmental conditions, including temperature, relative humidity, and wind direction and speed at the time of sampling as well as the process parameters, including equipment and proppant amount, type and mesh size can significantly affect the amount of the silica in the breathing air of the worker, multiple samples are required to assess risk. Collecting samples to measure worker exposures to chemical hazards at a hydraulic fracturing work site is a complex process. It requires the collection of a known volume of air from the worker's breathing zone that is passed through the collection media at specific flow rates. The media is then analyzed for the chemical agent, using a validated method, in an accredited laboratory. The result of the sample is then compared with the authoritative occupational exposure limit, such as an Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) or the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV).

The third category includes uncertain occupational exposure risks to novel hazards including advanced lubricants and engineered proppants. Little, if any exposure assessment information has been published and, in most cases, authoritative OELs and sampling and analytical methods have not been developed. This, however, does not mean that the materials do not present a potential risk from occupational exposure.

BVNA's process for assessing chemical exposure risks to workers on hydraulic fracturing work sites can be summarized in four steps:

1. Identify and collect information about the chemicals and chemical products used at the site;
2. Identify the processes and activities that can result in worker exposures;
3. Characterize the potential exposures to dusts, mists, fumes, vapors, and gases that must result from the handling or processing of these chemicals and chemical products;
4. Recommend appropriate elimination, substitution, engineering, work practice and personal protective equipment controls, based on the exposure risks.

Adding to the complexity of occupational exposure assessment at hydraulic fracturing sites is the employee status of the workers. In the United States, the oil and gas extraction industry employed approximately 200,000 people in 2013 (BLS 2014[ii]). Many of these workers are temporary full-time workers that travel between sites, often working in one location six months or less. Other factors that add complexity to the hydraulic fracturing occupational risk assessment process include the employer-worker relationship. Sites typically are multi-employer making it difficult to identify the on-site competent person who can ensure that work methods are followed and personal protective equipment is worn. Contract laborers are often used as well, creating gaps in the ability to communicate hazards and manage the medical surveillance aspects of exposure risks. No published study has identified the average expected length of employment and cumulative exposures of potentially silica exposed personnel in the hydraulic fracturing industry. The transient nature of the industry workforce, and its impact on cumulative exposure risks, may distinguish the fracturing industry from the various stable employment sites in mining, milling, construction, and manufacturing that have been the subject of many silica studies over the last 50 years.

Methods

Bureau Veritas North America (BVNA) occupational hygienists routinely conduct employee exposure assessments on behalf USA operators and service company personnel. BVNA occupational hygienists' exposure assessment methods are specified in the BVNA Technical Operations Manual that is aligned with the American Industrial Hygiene Association (AIHA) exposure assessment methodology (AIHA 2006[iii]). A comprehensive exposure assessment for hydraulic fracturing begins with a full understanding of the chemical, physical (including thermal), and biological agents at the worksite. Since a variety of hydraulic fracturing fluids are currently used, the occupational hygienist must begin the chemical exposure assessment process by reviewing the Safety Data Sheets (SDS) for the fluids and discussing other additives that may be used with the site responsible person. SDSs and technical data sheets are also reviewed for lubrication fluids and proppants. The exposure assessment process also includes physical hazards, such as noise, vibration, heat and cold stress, NORM, and musculo-skeletal hazards. Finally, a comprehensive risk assessment approach also includes hazards association with poisonous plants, snakes, and insects. This paper focuses on the chemical exposure assessment process primarily related to silica exposures due to the handling of proppants.

Following a review of the chemical hazards, the job titles/job responsibilities of the potentially exposed workers are identified along with the frequency and amounts handled. The work activities with the hazards are observed to identify specific tasks that can result in exposure via the inhaled, skin or eye routes in order to group potentially exposed workers into similar exposure groups (SEGs). This is an essential component of the risk assessment process since it will support the development and implementation of exposure controls for all workers on site, not simply the workers for which personal exposure monitoring has been conducted.

In the USA, OSHA has grouped workers on hydraulic fracturing work sites into three exposure groups. The first group, Ancillary Support Workers, includes Chemical Addition Operators, Hydration Unit Operators, and Line Bosses. The second group, Fracturing Sand Workers, includes Water Tank Switchers, Sand Mover Operators, Blender Operators, Groundsmen, and T-Belt Operators. The third group, Remote/Intermittent Support Workers, includes the rest of the job titles, including Sand coordinator, Sand Delivery Truck Driver, Mechanic, Service Supervisor, QC Technician, Wireline Operator, Safety Specialist, Equipment Operator, and Electronics Technician.

Accurate identification of SEGs supports the occupational hygienist's ability to recommend appropriate exposure controls for the SEGs with exposures greater than 50% of the authoritative OEL, focuses our exposure sampling on the SEGs with uncertain exposures (estimated at 10 – 50% of the OEL) and also supports our periodic exposure assessment schedule for the SEGs with acceptable exposures (estimated at less than 10% of the OEL).

The method to collect samples to quantify exposure risks requires rigorous attention to details. Silica exposure monitoring is conducted by collecting the total amount of dust and the respirable fraction in the worker's breathing zone, using personal sampling pumps calibrated to maintain the appropriate flow rates. The respirable component requires the use of a cyclone. The cyclone separates dust particles according to size. The respirable particles collect on a filter for analysis while the larger particles fall into the grit pot of the cyclone assembly and are discarded. The samples are analyzed at an AIHA-accredited laboratory using NIOSH methods 0600 (gravimetric), 7500 or 7602, or OSHA ID 142. BVNA also analyzes the samples for silica polymorphs, analyzed by X-Ray diffraction.

Interpretation of the sample results requires careful consideration of the factors discussed earlier, including weather, wind speed and direction, proppant amount and mesh size, and the exposure controls that were in place during the assessment. The outcome of the exposure assessment is a recommended plan to either continue the current exposure controls or mitigate unacceptable exposures using the hierarchy of controls.

Results

BVNA's exposure assessment process results in the development of recommended exposure controls.

To mitigate potential health risks from exposure to silica, the USA hydraulic fracturing industry is implementing feasible controls. Accepted industrial hygiene practice prioritizes the selection of industrial hygiene exposure controls using a hierarchy. At the top of the hierarchy is the elimination of the hazard, followed by substitution of the hazard with a process or material that is inherently less hazardous. Elimination of silica proppants is not currently a feasible control approach. Substituting silica with alternative proppants, such as resin coated or ceramic proppants, may reduce respirable crystalline silica exposures by reducing the generation of respirable particulates. However, both types of proppant still contain crystalline silica and the resin coatings may present their own health or environmental hazards.

Engineering controls that either provide a barrier between the worker and the hazard or physically remove the hazard from the air a worker breathes is the next level in the hierarchy. This is followed by worker training and work practices, which support controlling the exposure to the health hazard, and administrative controls, which limit the amount of time a worker spends in the hazard area. Finally, the least desirable control is the reliance on personal protective equipment (PPE). Identification of the points of dust generation is an essential component to the design, specification, installation, and verification of engineering and work practice controls. Esswein, et al. identified eight points of dust generation present during hydraulic fracturing operations (Esswein 2013[iv]). BVNA has identified a ninth dust release point that should be considered relating to spill clean-up. When sufficient amounts of sand are spilled, the piles can interfere with operations and workers must remove some of the spilled proppant. The dust release points are:

Dust generation points associated with sand mover loading including:

1. Inspection hatches on top of sand movers;
2. Fill ports on sand movers.

Dust generation points associated with pumping a hydraulic fracturing stage (pumping operations) including:

3. Delivery conveyor belt under sand movers;

4. Sand dropping from delivery belt (dragon tail) to the transfer belt (t-belt);
5. Sand moving along the t-belt;
6. Sand dropping into the blender hopper from t-belt and into the mixing tub from the sand screws.

Dust generation points outside the process:

7. Site vehicular traffic;
8. Release from work uniforms;
9. Other operations such as manual proppant handling (spill clean-up).

Designing out the potential for dust emission during proppant movement operations represents a significant challenge since the controls must be assessed for feasibility and effectiveness under varying site conditions. Replacement of existing equipment is not economically feasible in the short term, requiring a significant investment of capital for the testing, evaluation, production, and installation of new equipment. New sand moving equipment with enclosures and dust collection systems to new methods of delivering proppant are in development, however, since the current fleet of sand moving equipment is very large, other engineering controls need to be considered.

External enclosure and capture device systems, referred to as "wrap jobs" are available in the USA and control dust emissions from the sand moving process (sand mover loading and pumping operations) by the installation and operation of an external exhaust ventilation system including curtains, ducts, and a vacuum to provide air flow. The systems must be designed, tested, installed, and customized for each site since they must be adapted to specific equipment configurations.

Dust released from the proppant loading process can be reduced through a vacuum system and bag house that is attached to sand movers. The system draws air from the inside of the sand mover bins collecting dust and exhausting the pressure from the sand trucks. This allows the top hatches and unused fill ports to remain sealed during sand loading.

Dust emissions associated with mechanical action and drop points, such as those associated with pumping operations, may be addressed by passive enclosures such as stilling curtains, tent enclosures, or enclosed chutes. However, enclosing a point of dust generation prevents the dust from dissipating unless exhaust ventilation is present. A passive enclosure requiring entry for activities such as maintenance or clean-up may expose workers to higher concentrations of dust than would otherwise be present during these activities. Equipment under consideration for the use of passive enclosures require site specific evaluation to determine the level of control needed, their effective and feasibility and to ensure that they do not increase potential exposure risks from related hazards.

Where respirable silica levels exceed applicable limits, removing the worker from the dusty environment, into an enclosure that is supported with a positive pressure mechanical ventilation system, protects the worker without having to address each point of dust release.

Until these types of controls are implemented and the resultant exposure control is verified, other methods of control, including administrative, work practice, and respiratory protection will likely be required where worker exposures exceed applicable OELs.

One important work practice control is the need for removal of dust from workers' clothing. If the clothing is not cleaned, the silica containing dust can be a source of exposure by inhalation and may be transported off site, potentially impacting laundry services, families, and other individuals. Workers commonly use compressed air, brushes, or their hands to remove dust contamination from their clothing. This mechanical or pneumatic cleaning can release dust into the workers' breathing zones, resulting in additional exposure. The use of HEPA vacuums or commercially available air showers, followed by a removal and proper cleaning of the work clothing should be adopted.

Recent innovations to hydraulic fracture stimulation treatments, including high-performance proppants and novel micro-emulsion surfactants containing advanced materials, may introduce occupational health hazards that have not yet been fully characterized. Therefore, uncertainty about the appropriate exposure controls to mitigate the potential risks to worker health prompts the adoption of a robust management system to assure that worker health and safety is considered at each step in the development, use, and ultimate disposal of these materials and supports the ongoing re-assessment that is required as new information is developed about the hazards and new applications for this technology are commercialized, resulting in sustainable health and safety performance.

Conclusions

The US energy revolution has created a wealth of learnings which the world can leverage to reduce employee exposures during hydraulic fracturing and well activities. The corner stone is the anticipation and assessment of employee exposures which then provide the basis for effective control plans. Ensuring worker safety and health during shale reservoir stimulations operations requires a systemic approach for identifying health hazards associated with both known and novel materials, and assessing and controlling exposure risks.

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