GUIDELINES FOR COMPRESSOR PACKAGE SAFETY, INSTALLATION, AND SITING CONSIDERATIONS
Rev. 0; Issued Nov. 14, 2018

1. Introduction

This Gas Compressor Association Guideline is adapted from the much more extensive Gas Machinery Research Council, *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5], that was a collaborative effort involving member companies of both the Gas Compressor Association and the Gas Machinery Research Council. This Guideline is not intended to be an all-inclusive specification. The information contained herein provides a set of guidelines and what study results reflect as good practices pertaining to the siting and installation of high-speed reciprocating and rotary screw compressor packages for upstream field gas compression applications.

The Gas Compressor Association and the Gas Machinery Research Council make no representations, warranty or guarantee in connection with publication of these guidelines and hereby expressly disclaim any liability or responsibility for loss or damage resulting from its use or for any violation of federal, provincial or local regulations with which it may conflict.

The purpose of this guide is to help end users and operators achieve the best results from their gas compressor unit by providing safety, siting, installation, and operation guidelines. These guidelines are furnished to establish a minimum level of understanding and are not intended to replace or supersede the end user's own company policies and insurance guidelines, manufacturer's guidelines, construction or piping codes, safety regulations, federal, provincial, or local regulations, or most of all, common sense. Ultimate responsibility remains with the end user.

End user and rental fleet operating personnel should be made aware of, and become familiar with, the following information and the potential dangers around which they work. Proper training and continued awareness are critical factors for the prevention of harm to personnel and machinery. Although compressors are designed and built to high safety standards, it must be recognized that the safest machine is only as safe as the operator running it.

A compressor operator must always keep in mind that:

- The machinery is handling highly flammable natural gas, and as long as the natural gas is not allowed to escape and/or mix with air, it is relatively incombustible. However, if air is allowed into the system, an explosion could be possible. The system must be fully purged of all air before start-up and a positive pressure maintained within the complete system at all times while starting, idling, and running.

- Any gas (including air and natural gas) flows from a high pressure area to any lower pressure area. Therefore, any time the pressure in the gas system (i.e., compressor cylinders, main piping, bypass, vent piping, scrubbers and bottles) is lower than atmospheric pressure, the compressor will have a tendency to pull air into it. All possible points of entry must be closed.
- A combustible situation may occur if a gas pressure line breaks, generally due to machinery vibration, allowing pressurized gas to escape. If there is excessive vibration in the gas compressor package, it should not be dismissed as normal and acceptable. Take the unit out of service and, if applicable, contact the Compression Leasing Company for assistance in assessing the severity of the problem and to make any necessary repairs or adjustments to reduce the vibration to a safe level before resuming operation of the package.
- Personnel must always consider possible paths of escape if a fire, explosion or other emergency occurs. The area around the compressor must be kept free from trip hazards, machinery, debris, production equipment, and other sources of combustible material so that personnel may escape quickly.

2. Basic Safety Considerations

Safety is often referred to as common sense. There are many standard safety rules, but every situation is different, and not everything can be covered by rules. Therefore, experience and common sense are necessary guides for personal safety. Lack of attention to safety can result in accidents, personal injury, reduction in efficiency and worst of all, loss of life. It is critically important that equipment operators, maintenance personnel and supervisors constantly watch for safety hazards and correct any deficiencies promptly. Some important considerations include the following.

Provide safe access and egress. Proper planning must always include safe access and egress for a field gas compressor package. This includes ensuring a clear path of escape from any location around the unit in the event of an emergency. If the immediate area around the compressor is fenced or blocked by sounds walls, for example, suitable emergency exits must be provided. See OSHA General Industry 1910[8] Subpart E for detailed requirements on means of egress.

Never make mechanical adjustments or repairs to a machine while in operation. Always stop the engine (or electric motor driver) before cleaning, servicing, or repairing any mechanical equipment on the compressor package. Place all controls in the “off” position and properly Lock Out / Tag Out to prevent accidental restarting. Before restarting, make sure that all tools and other material are removed from the engine, compressor and other equipment.

Provide for crane access. It is also important to recognize that compressors require service and repairs, and maintenance personnel must have appropriate cranes at the installation or clear access to get a service truck with a crane close to the unit, for efficient and safe lifting of components.

Keep the compressor package area clean. Keep the compressor package area as clean and clear of objects or debris as possible.

Do not wear loose clothing, neckties, rings, wrist watches, bracelets, hand rags, etc., around machinery.

Replace damaged fans immediately. Replace damaged fan blades promptly. If a fan blade or fan drive shaft is bent or damaged in any way, it should be replaced. Do not attempt to repair or use the damaged parts unless approved after inspection and approval is obtained from the manufacturer or an OEM certified service provider. Fan assemblies must remain in proper balance. When damaged, an unbalanced fan can fly apart during use, creating an extremely dangerous condition.

Provide proper ventilation. The exhaust products from internal combustion engines are toxic and may cause sickness, injury or death if inhaled. All engine installations, especially those within a closed shelter or building, must be equipped and maintained with an exhaust discharge pipe so that the exhaust gases are delivered into the outside air. A closed building, enclosure or shelter must be adequately vented and ventilated. A means of providing fresh air into the building, enclosure or shelter is necessary.

No smoking. Never smoke (or have open flame) on a compression location at any time.

Avoid ignition shock. Avoid touching breaker-less magneto and battery ignition systems as they can cause electrical shocks.

Cool down before servicing. Always allow the compressor package to cool before servicing. Wait until the engine and coolant have cooled before removing radiator or surge tank caps. Always replace weak hoses, lines, and fittings.

Provide adequate fire protection. Fire extinguishers must be easily accessible and their locations clearly marked. Keep routes of emergency escape from the compressor package installation clear and free of obstructions.

Safety guards must be kept in place at all times during equipment operation. When safety guards have to be removed for equipment maintenance, Lock Out / Tag Out procedures must be followed.

Safety equipment must be worn at all times. Safety equipment, such as hearing protection, safety glasses, hard hats, fire retardant clothing, safety boots or shoes, and portable gas detectors are recommended and may be required by local, state, provincial and federal regulations and by insurance carriers.

Visual inspections. Prior to starting and periodically during operation, operators must walk around the compressor package and visually inspect the unit for broken or loose fasteners and components, tools, open valves, missing equipment, etc.

Do not modify the compressor package. There are to be no modifications to leased compressor packages, except by the Compressor Leasing Company. For modifications to end-user owned compressor packages, consult the original packager for guidance. Improper modifications can invalidate vessel and piping codes and can pose potential hazards to personnel and equipment.

Do not tamper with, modify or bypass package safety and shutdown equipment. The compressor package is designed and equipped with safety equipment for the protection of equipment and personnel. No modifications to or bypassing of the compressor package shutdown or safety systems are to be made.

Do not exceed maximum allowable pressure and temperatures. Be sure that all maximum allowable pressures and temperatures are not exceeded when starting, running, stopping or bypassing flow around the compressor package. Serious equipment damage and personnel injury could result should maximum allowable pressures and temperatures be exceeded.

Awareness of gas content and cleanliness. Unless specifically indicated, the compressor package is designed to be operated with and to compress sweet, clean and dry natural gas containing no hydrogen sulfide (H_2S), carbon dioxide (CO_2), or air. The Compressor Leasing Company, or the original compressor packager in case of end-user owned packages, must be consulted in advance for additional guidance should operation with any amount of H_2S or with more than about 2% of N_2, CO_2 or air become necessary. Gas supplied to the engine and the compressor should be free of liquids, solid particles and any other contaminants.

<u>Follow Lock Out / Tag Out procedures for the company and specific location.</u> All field gas compressors should be equipped with energy isolation devices and basic instructions on how to use these to control all energy sources present during servicing and maintenance. Figures 1 and 2 are an example of a basic procedure. Figure 1 shows a Lock Out / Tag Out instruction decal applied to the control panel door, with the detail of the decal shown in Figure 2. Some machines may require a more complex, specific procedure.

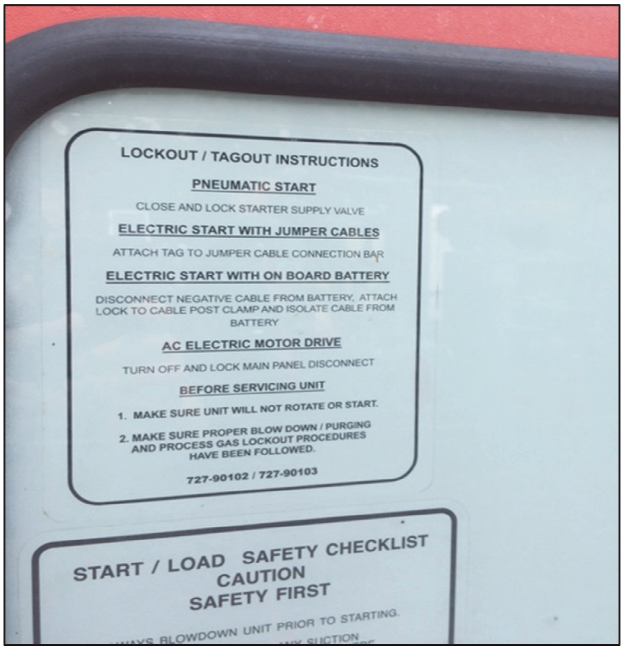

Figure 1: A Lockout/Tag Out instruction decal applied to the control panel door.

Figure 2: Close-up of the instructions on the decal in the panel door on Figure 1.

The following parts of this Section provide additional guidance.

2.1 <u>Package Access and Trip Hazard Avoidance</u>

One of the most common safety hazards for field gas compressor maintenance personnel is trip hazards. Figure 3, obtained from an accident report for a Lost-Time injury, shows an example of very poor and unsafe surface piping, with several trip hazards. As much as possible, a clear, level, path of travel must be provided in the immediate area all the way around the skid, free of holes or other hazards. Most trip hazards can be eliminated during the initial site set-up.

Figure 4 is a much better example. Piping is painted a bright color, partially buried and routed to allow a clear path of travel and emergency escape around the entire compressor package. Figure 5 shows the application of gravel under way, installed to cover piping around a new compressor installation to provide a safe trip-free travel path. Figure 6 shows oil supply tanks that are equipped with brightly painted pipe, with the horizontal runs installed subsurface to the package, eliminating the need for hoses and their associated trip hazards. Installation of piping, tubing and hoses should be sub-surface, with an elbow or bend installed close to the skid for the lines to connect. As-built P&IDs are recommended for all connection piping, especially buried lines. Ground rods should be located out of the footpath, and capped or covered. Use bright color paint, such as Safety Yellow, to highlight any object that could present a trip hazard.

Suction and discharge piping must be buried, supported, or otherwise adequately secured to prevent vibration. Note the use of a stanchion to support suction piping in Figure 4. When bracing piping, shims should be used as needed to ensure continuous contact and avoid vibration problems. One common practice is the use of concrete blocks, such as parking lot curbs, to support piping headers. Another excellent solution is the use of pipe racks. Always avoid locating piping or pipe racks in such a way that it presents a hazard and/or blocks access where needed. Regardless of the chosen method, service truck or crane access and other safety requirements must be a key factor in planning compressor connection and piping support.

Figure 3: Example of an unsafe surface piping installation with trip hazards.

Figure 4: Example of a much better installation that allows a clear path around the package.

Figure 5: Gravel being installed to cover piping around a new compressor installation.

Figure 6: Example of oil supply pipes run subsurface to skid, avoiding tripping hazards.

2.2 <u>Fire Protection</u>

All field compressor installations, whether inside buildings or enclosures or outdoors, must be considered and clearly identified as a "No Smoking" area. Unless suitable hot work practices are taken, no ignition sources are allowed anywhere around the unit. An adequate number of fire extinguishers should be provided, for any small, incipient stage fires that may occur. These should be locate at accessible locations, a safe distance away from likely sources of fire. See OSHA[8] Subpart L for detailed requirements on fire protection.

2.3 Site Lighting

Adequate lighting is also critical to avoiding trip hazards and enabling safe movement around field gas compressors. If compressor servicing and repair is expected to take place during darkness, a suitable means of lighting is strongly encouraged. Artificial lighting should also be provided for compressors enclosed in a shelter or closely blocked-in by sound or wind walls, as natural light and/or work lamps on service trucks will likely be ineffective. Providing a means for lighting to be switched on/off by compressor operators as needed can help alleviate problems with insects and other concerns.

2.4 Pressure Ratings and Pressure Relief Protection

It is imperative to always verify maximum working pressure (MAOP) ratings before installation of any piping, tubing and hoses. Threaded suction and discharge piping connections are discouraged as breakage may occur due to vibration and/or stress as the skid or foundation settles. Pipe nipple failures have been the cause of many leaks and fires. Because of the inherent vibration associated with reciprocating compressor packages, improperly designed or installed nipples are subject to breakage by fatigue. Section 14.3.5 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*,[5] contains detailed best practices for this common problem component.

Figure 7: A small PSV mounted on top of a suction scrubber.

Figure 8: Pilot-operated PSV mounted on suction piping off-skid.

It is also imperative to ensure that an adequately sized pressure relief valve, or pressure safety valve (PSV) is present between the suction block valve and the compressor's 1st stage suction scrubber. This PSV should be sized to protect the package from a failed suction control valve with maximum differential pressure or the maximum flow of the upstream gas source. The PSV should be set to relieve at a pressure equal to the lowest of the MAOPs of the suction scrubber, the 1st stage cylinder and any suction piping on or off the skid.

Many field compressor packages have a place on the scrubber to install this PSV, as shown in Figure 7. For larger PSV sizes or when longer vent stacks are required, vibration may be a problem. Rather than mounting on the scrubber, a better practice is to mount the PSV on a supported area of the skid with pipe from the process gas line to that point. In that case, it may have to be installed on the suction piping off skid, such as the pilot-operated PSV shown in Figure 8. All PSVs must be mounted and braced securely enough that the weight of the valve and associated piping, as well as the normal vibration and forces applied during operation, do not overstress the relief valve's threaded connection. See Sections 10.5 and 12.4 of the *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] for further guidance on PSV mounting.

2.5 Energy Isolation Precautions

Consideration must be given to energy isolation, commonly referred to as Lock Out / Tag Out, requirements when setting up the site. All valves used in compressor connections should be a lockable type valve. For discharge piping, a full opening, lockable block valve is required downstream of the check valve. For suction piping, a full opening, lockable block valve must be inserted in the line downstream of the station separator or suction header, as close to the compressor package as possible.

2.6 Safe Location of Vents

Most compressor packages have PSV vents, blow down vents, packing vents, and air/gas starter vent lines. To prevent fire and explosion hazards, these vent lines must be piped a safe distance or height away from the compressor unit, and any potential ignition source. Avoid locating vent discharges next to work platforms or other places where personnel routinely, or even occasionally, have to work. Air/gas starter gas vents should be piped separately, with adequately sized lines, to ensure proper operation of the starter and to prevent the starter vent line flow from interfering with the venting of other devices. Most vent lines and drain lines should not be connected together into a common header*.

*Note: For low or non-pressurized lines, some acceptable common header examples exist. Compressor packing and guide vent lines are frequently connected to one common drain.

2.7 Hydrogen Sulfide (H_2S) Exposure Avoidance

Hydrogen Sulfide (H_2S) is an extremely toxic, highly flammable, colorless, heavier-than-air gas that can cause death at low concentrations (400 to 600 ppm). It is commonly found in many producing oil and gas formations. H_2S is also referred to as sour gas, poison gas, rotten egg gas, acid gas, sewer gas, and sulfur gas. Typically, if the concentration of H_2S is over 10 ppm, then special precautions must be taken in both the design and operation of the package. It is beyond the scope of this document to cover these in full, however some general considerations are provided.

1. Refer to Sections 10 and 11 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5], which provide further guidance on design considerations and requirements regarding H_2S. In addition, it is important to always follow manufacturers' recommendations for package components.
2. Operational considerations will vary depending on the exact concentration, the installation's setting (i.e., enclosed vs. non-enclosed) and applicable state and/or local rules and regulations. Periodic gas sample analysis, leak testing and site surveys, radius-of-exposure calculations, warning signs, windsocks, fixed monitoring stations, portable monitors, emergency breathing-air equipment, and the use of the buddy system to ensure that no worker is on site alone are all basic H_2S safety practices that may be required to protect personnel at a field compressor site having H_2S levels above 10 ppm. ANSI/ASSE Standard Z390[1] provides detailed recommended practices on protection of personnel from H_2S gas. Site and compressor operators are strongly encouraged to refer to ANSI Z390 and/or consult

with hydrogen sulfide safety professionals when actual or potential H_2S exposures could exceed 10 ppm.

3. Site Layout and Preparation Requirements

In field gas compression applications, the site operator and the compressor operator are often different parties. When this is the case, good communication is very important in preparing the site for a compressor installation. Some of the topics that must be considered for site layout and preparation are discussed in this Section.

3.1 Physical Location Considerations

When designing a field compression site, consideration should be given to the proximity of compressor packages to access roads. It is convenient for operating and maintenance personnel to have them close to roads. Heavy equipment is periodically required for compressor servicing. Access roads and the location around the unit must be prepared and sufficiently maintained to support truck traffic. However, these roads are typically dirt or gravel, and they can introduce excessive dust that can foul engine inlet air filters. Road dust can also contribute to fouling of fins on air-coolers, requiring more frequent cleaning to maintain acceptable cooler performance.

Directional orientation is also an important consideration when setting compressor packages. The cooler should always face the prevailing winds during summer months. The direction of prevailing winds varies at different locations and geographic regions. This should be investigated and confirmed prior to installation.

To avoid unintentional warm air recirculation or unnecessary air restriction, proper clearance must be maintained around air-cooled heat exchangers. Sound walls, containment walls, firewalls, buildings and exhaust air from other heat exchangers are examples of items that can negatively affect a cooler's performance. Section 6.4 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] provides additional guidance. When uncertain, consult with the cooler manufacturer and/or compressor packager, and follow their recommendations.

Figure 9: Locating compressors inside a containment wall inhibits truck/crane access.

Figure 10: A layer of sand added over a plastic liner helps reduce slip/trip hazards.

Although environmental protection is an important consideration that must be addressed at production sites, a balance must be maintained with safety. For example, as shown in the example in Figure 9, containment walls or berms placed around a field gas compressor package block access by service trucks, and inhibit access by personnel. In this case, a crossover stairway has been provided to enable personnel access, however, the wall still interferes with truck and crane access, and it requires that personnel carry heavy parts up the stairs and over the wall. Figure 11 shows another example of an installation that inhibits access to the compressor package for operation and maintenance.

Figure 11: The location of this compressor package in the corner of a containment berm with fencing inhibits access and quick exit by operators in an emergency. The surface piping poses a trip hazard.

Figure 12: The concrete curb around this compressor package trapped oil and rain water, causing an injury when an operator tripped over a hidden obstacle and fell.

Liners placed under the compressor package, as shown in Figure 10, can create a slippery surface when water or oil contacts them. In this case, placing a layer of sand on top of the liner greatly improved the safety for personnel needing to walk around the compressor package. End users are encouraged to work with compressor operators during the selection of environmental protection methods to ensure that the chosen method is workable for operator and maintenance technician access, so that the equipment can be properly maintained.

Safety precautions must be taken when locating the compressor on a field location with ancillary production equipment. For example, dehydrators and flare stacks are potential ignition sources. These should be a minimum of 25 to 50 ft. away from the compressor package, depending on the site layout and other considerations. Prevailing wind direction, as well as heights and gas density, should be taken into account for compressor vents when ignition sources are present on location.

Flammable and combustible liquids containers, such as methanol, glycol and lube oil, can contribute to a compressor package fire and spread it quickly. These should also be located a safe distance away from the unit or separated by a fire-resistant barrier.

Follow the site lighting guidelines provided in Section 2.3.

3.2 Pad and Foundation Installation

Field gas compressor pads and foundations vary greatly as discussed in Section 8 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5]. The size and type of unit, the geographical location and the soil characteristics are important factors that influence the type of pad or foundation. In general, compressor pads must be level, promote good drainage, and firmly support the entire compressor skid at all points, without being affected by vibration or weather conditions.

Depending on the design and size of the compressor package, there are a variety of pads and foundations that are utilized. These may range from a sand box, gravel or caliche pad design to a reinforced concrete foundation. Although the guidance from a qualified geotechnical consultant is best practice for selecting an appropriate type of pad or foundation, the selection flow chart in Figure 8.8 in *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] can provide initial guidance.

Gravel for use as a base for compressor package pads is crushed gravel or "crusher run" gravel, which is a mixture of smaller crushed gravel sizes and sand. Gravel that contains mostly round elements is not suitable for compressor pads, as it acts like a stack of marbles, which cannot be compacted into a stable base. Also, use of large rocks should be avoided, as they create a trip hazard. Section 8.3.2.4 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] provides extensive details for various types of caliche or gravel pads.

For rental/leased compression units, which are typically temporarily or only semi-permanently installed and required at a particular site, gravel or caliche pads are preferred. However, when such pads are not deemed adequate, and where the soil condition does not require piles, reinforced concrete pads or foundations are often used. Most field compressor skids are designed for an outdoor, "field" setting, and therefore should not be set on a concrete slab without an insulation material of at least ½ in. thickness. When using a concrete foundation, to ensure that the compressor is properly set on the pad, and to allow for "waves" in the concrete, it is a good practice to grout the skid to the foundation. Typically done for larger units, grouting should only be done by experienced personnel. Depending on the duration of the project, grout can be a 12 sack-sand-cement mix, or epoxy. It is important to remember that upon removal of the compressor, the grout will have to be chipped out prior to shipment. Section 8.3.2.1 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] provides extensive details for reinforced concrete block foundations for field gas compressor packages.

Figure 13: The end of this compressor skid is not well supported.

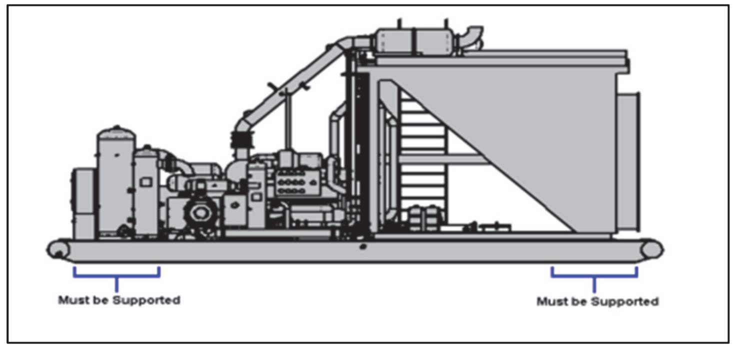

Figure 14: Supporting only the center of the package leads to vibration. The ends must be supported as well.

Figure 15: Compressor package and off-skid horizontal coolers both mounted on screw piles.

Figure 16: Non-permanent (e.g., rental) package on a swamp base foundation.

Regardless of the pad design, the entire field compressor package skid must be adequately supported at all points. Figure 13 shows an example where the end of the skid is not supported. Figure 14 emphasizes the need to ensure that ends of the compressor package skid, as well as all other points, are well supported.

Screw piles are a cost-effective solution for many compressor applications. However, they do present a risk of vibration due to lack of mass. Like all foundations, screw piles should be an engineered design for the specific compressor and location. Figure 15 shows a gas compressor package with both the package and the off-skid horizontal coolers mounted on screw piles. Sections 8.2.2.2 and 8.3.2.3 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] provide guidance on the use of driven pile and engineered screw pile applications, respectively. Another type of foundation, often called a swamp base, is shown in Figure 16 in an installation in Southern Louisiana. This approach helps distribute the load for non-permanent (e.g., rental) compressor packages on gravel pads used in less than ideal soil conditions.

3.3 Noise Avoidance and Control

The requirement for noise avoidance and control has become more of a factor for field compression due to the increased proximity of compressor locations to populated areas.

3.3.1 Noise Measurement

Sound is produced by vibration and needs a medium to travel from one point to another. Unwanted sound is referred to as noise. All noise sources, like engine exhaust outlets, emit sound energy that propagates in all directions. The total sound energy emitted by a source is called sound power. Sound power is independent of distance as it is the total energy. Sound pressure on the other hand, is distance-dependent, and as the distance between the sound source and listener is increased, the sound pressure level goes down. Also important is the DNL (day-night average sound level), which represents the impact of a constant sound for an entire day. Most field gas compressors operate continuously, and changing day/night conditions affect the sound pressure travel.

It is important to account for cumulative noise effects from other various noise sources when conducting sound pressure surveys of compressor equipment. This can be the numerous noise sources on a single compressor package, or, when multiple compressor packages are located in one location, each noise source on each unit contributing to the overall noise level. As noise is energy, all sound pressure levels are logarithmically added to get an overall noise level at a set distance. When setting a target for a new noise source at a property line, for example, the cumulative effect must be considered.

Sound pressure level readings should be consistently recorded at a set distance. State or local ordinances, company policies and other resources should be followed, but generally accepted practices include "at-10 ft." or "at-property-line".

A field compressor package has several sources of noise during normal operation. These include, but are not limited to, the engine, compressor frame, air-cooled heat exchanger and auxiliary motors, valves and controls. Although typically of only a short duration, compressor purging/blowdown, pressure relief valves (PSV) and pneumatic starter exhaust vents can create very high noise levels during operation and when open to atmosphere. During abnormal operation, additional items can contribute to noise levels. These include excessive vibration due to items out of balance, fan blade pitch, faulty bearings, and recycle valves cycling, among other things.

3.3.2 Noise Reduction Techniques

There are varying methods to mitigate noise levels after a compressor package is placed into operation. However, there are often more options available if noise avoidance and control is planned at the design stage, before installation. Reduction of the rated horsepower can occur during some methods of reducing engine and compressor package noise levels. Consult the relevant engine, cooler, compressor and/or packager for guidance before making modifications.

Exhaust silencers (mufflers) are used to reduce the noise of most engines. Smaller units have the silencer mounted directly to the engine. Medium to larger packages are often designed to have the silencer mounted on top of the cooler. Some applications require the silencers to be mounted off-skid as shown in Figure 17, typically to reduce sound pressure travel. This particular installation placed the silencer at ground level to reduce sound travel over walls at an urban golf course. Since silencers produce high levels of heat, care should be taken to protect personnel from exposure during maintenance when mounted lower to the ground or work surface.

Silencers are classified by grades and range from Industrial (lowest grade) to Extreme (highest grade). Although "hospital grade" has become a common term in the industry, it is important to remember that silencer manufacturers may have similar grades, but the range of attenuation for each grade is not regulated. Often in a remote application, ordering silencers by grade is not sufficient. A better approach is to know and specify the desired decibel reduction level, e.g. a sound pressure level of 85 dBA at 10 ft. Also, site conditions can impact the proper sizing of silencing equipment.

Intake silencers are used to mitigate the noise of engine air intakes. Normally, absorptive silencers are used. Use only intake silencers manufactured such that fibers cannot come out of the silencer and be ingested into the engine.

Figure 17: An exhaust silencer at ground level reduces sound travel over walls at an urban golf course. Insulation or a personnel barrier is missing.

Figure 18: An off-the-shelf silencer for gas exhaust vents, such as PSVs.

Silencers are available for compressor purge/blowdown, PSV, and pneumatic starter exhaust vents. Due to the high noise level produced by these sources, vent silencer devices are recommended for compressors located near populated areas. A commercial silencer for a gas exhaust vent is shown in Figure 18.

For air-cooled heat exchanger noise, lower levels can be achieved in different ways. Once again, more options are typically available when noise control is addressed during the design stage, e.g., specifying a quieter cooler with a slower fan tip speed and more heat exchanger surface area before the package is ordered. Other options are listed below. The cooler manufacturer or packager should be contacted for guidance, as most noise reduction methods can affect thermal performance. Options include slowing down the fan speed by utilizing different sheave ratios or a variable speed drive, adding a conical or belled fan ring inlet, installing fan ring inserts to reduce tip clearances, or utilizing a different fan, such as one with more blades, to maintain airflow volume at a lower tip speed.

3.3.3 Sound Walls

After equipment has been placed in service, sound walls can be strategically placed for optimum effect to further reduce the noise levels of an overall system. For reasons such as wind loading, support structure and obtaining proper noise reduction levels, sound walls should be designed, built and installed by qualified, experienced personnel. Sound walls and sound mitigation enclosures can greatly reduce accessibility to equipment and create numerous safety issues for service personnel. They can also disrupt airflow for coolers and negatively affect heat exchanger performance. It is recommended that service personnel be involved in sound wall installations, to achieve the best overall outcome.

Additional information and guidance on noise avoidance and control can be found in Section 10.9 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5].

3.4 Compressor Package Shipping and Unloading

When obtaining a bid for a gas compressor package, it is advisable to request itemization from the vendor for any costs that may be incurred after completion of the packages. Such charges can include disassembly, shipping covers or tarps, and cranes for loading/unloading. These charges may not be included in the vendor's bid unless requested.

Personnel safety is critical during compressor unit loading or unloading, and all safe lifting, rigging and construction practices must be followed at all times. Many field gas compressor packages are smaller horsepower units that are loaded and unloaded with a tailboard winch truck. Figure 19 shows hazard zones which personnel must avoid for safe tailboarding operations. Areas in front of the truck cab, and all around the compressor are danger zones during tailboard loading or unloading. A snapped winch line or unexpected movement of the load could result in a serious injury or fatality. Personnel must stay clear of these areas.

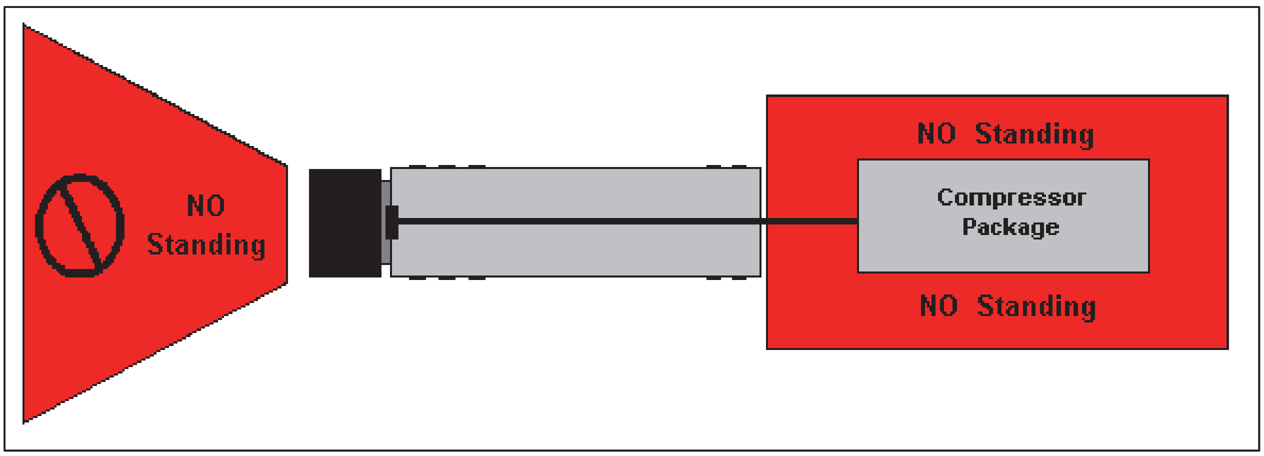

Figure 19: Areas in front of the truck cab and all around the compressor package are danger zones during tailboard loading or unloading. A snapped winch line or unexpected movement of the load could result in a serious injury or fatality. These areas must be kept clear of personnel.

Prior to delivery to remote locations and/or new construction sites, it may be beneficial to request the trucking company to perform a route survey in order to confirm that the proposed trucks and trailers can navigate any challenges that may be along the route. Examples include roads that are unpaved, rough, narrow, muddy, or snow-covered; steep grades; sharp turns; narrow or low bridges; etc.

The package equipment must be prepared for shipment to prevent corrosion. This includes disassembly as needed for shipping and installation of watertight covers on all openings. It is important that the end user confirm that the unit is properly protected for long term or outdoor storage if it is not immediately destined for installation.

In order to avoid improper identification, handling, storage, or installation of the ship loose materials at the construction site, the following documentation should be provided with sufficient description: storage and installation procedures, material packing lists, drawings, bills of material, and labeling/tagging of the ship loose materials. It is also good practice to make a photo record of all shipped materials, including small ship loose items, prior to shipment. Additional documentation guidelines are provided in Section 15 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5].

Equipment and/or skids should be outfitted with necessary lifting lugs to allow ease of unloading and installation in the field. Package and equipment vendor drawings should identify the equipment weights and location of lifting points so that the proper rigging (slings, spreader bars, etc.) and equipment for unloading can be arranged at the construction site. For larger horsepower units, identify the correct lifting lugs on the compressor package and their load rating, as well as the center of gravity.

Sufficient prior notice should be provided to construction crews so that the necessary equipment will be ready when the compressor package arrives. Only experienced and qualified personnel should be used for inspecting the package upon receipt and unloading the package and associated equipment. The load ratings of the proposed rigging and lifting equipment must be verified and inspected for suitability and condition prior to unloading.

The field gas compressor access road and construction site should be compacted sufficiently to support the incoming loads. Insufficient compaction of the soils could cause loads to shift and become unstable. For packages requiring multiple shipments and deliveries, it is recommended to communicate with the construction site the total number of trucks that will be arriving, clarify what equipment is on each truck, and to coordinate the delivery sequence of each truck.

Once received and unloaded at the construction site, the shipped-loose parts should be properly stored and protected from water damage until they are ready to be installed on the package. Be aware that smaller items are often shrink wrapped, boxed, or otherwise combined together and secured against being lost in transit. Always visually check all items received against packing lists or other documents.

If the package and other equipment have been unloaded and stored for a longer period of time than originally anticipated or intended, disassembly for inspection will be necessary before proceeding. Equipment must be carefully inspected to confirm that it has not been contaminated or experienced water damage, corrosion or other physical damage during the transportation, handling and storage processes. To reduce contamination of open equipment, cleanliness must be paramount throughout the process. This is always a challenge at a construction site, and it requires special effort.

3.5 Compressor Package Installation and Piping

Depending on the size of the unit, a field compressor package may be shipped as one complete unit, or it may be partially disassembled for shipment. Generally, larger packages have the cooler and ancillary items removed and shipped separately, while smaller packages are commonly shipped as one complete package. Smaller compressor packages are normally tailboarded with a winch truck as shown in Figure 20, or they can be moved in a single lift by a portable crane as shown in Figure 21.

As shown in Figures 22 and 23, larger horsepower packages generally require partial disassembly, due to size and weight considerations. This introduces the need for extra inspection and careful reassembly at the site. The level of field reassembly varies from package to package, so not all of the following guidelines applies to every compressor.

Figure 20: Smaller compressor packages are typically tail-boarded with a winch truck.

Figure 21: Smaller compressor packages can normally be moved in a single lift.

Figure 22: Larger horsepower packages are generally too heavy for a single lift.

Figure 23: Larger horsepower packages generally require partial disassembly due to size and weight.

3.5.1 Piping Contamination

All piping should be checked to verify that it is free of foreign matter such as sand, rust, mill scale, metal chips, weld spatter, grease and paint. Proper cleaning procedures must be used with appropriate cleaners, acids, and/or mechanical cleaning to meet cleanliness requirements of the manufacturer's specifications. Even with the best cleaning efforts, construction debris may still be present in the piping upstream of the package. Therefore, before start-up, it is important to install inlet gas debris strainers with 150 micron (100 mesh per inch) screen and perforated metallic backing in a pipe spool upstream of the 1st stage scrubber.

Figure 24: A debris basket strainer installed in a suction scrubber inlet.

Figure 25: To avoid excessive strain, piping flanges must be well-aligned before assembly.

Installation of a strainer in the suction bottle outlet nozzles is also good practice to trap any welding debris inside the bottle. Common strainer devices include cone strainers (often called witch's hats), tee strainers and basket strainers. All of these can provide effective and economical protection of compressor cylinders. It is important to note that most strainers are intended for temporary use only. Common protocol is to remove strainers after 60 days of operation, or as soon as they are no longer collecting debris, to prevent future blockage or disintegration problems. However, some end users and operators prefer to keep strainers in place permanently. In that case, the strainers must be designed for permanent operation, which will typically change the required surface area. Consult with the strainer manufacturer for appropriate guidance. Regardless of temporary or permanent installation, the differential pressure of all inlet strainers should be monitored and they should be cleaned regularly before the differential approaches pressure at which the screen will collapse. To protect against screen collapse, high differential pressure alarm or shutdown switches can be used. Figure 24 shows a debris basket strainer installed in a suction scrubber inlet.

3.5.2 Piping Alignment and Support

To avoid excessive strain, piping flanges must be well aligned before assembly. Excessive gaps, angular misalignment or linear misalignment, such as shown in Figure 25, must be avoided. Using a pry bar to align flange bolt holes, or "drawing down" to pull piping into position is unacceptable. Before torqueing, flange bolts should be threaded into holes by hand with no contact with the flange occurring. The gap between flanges before applying torque to the bolts should not exceed nominally 0.020 in.

Piping must be supported and secured in accordance with good engineering practice. All piping 2 in. diameter and above should be mounted using band clamps or pipe straps on I-beam support, as shown in Figure 26. Note the rounded corners for safety purposes. U-bolt style clamps should only be used for pipe under 2 in. diameter. Install Fabreeka or an equivalent material between the clamp and pipe to prevent paint damage, fretting and corrosion of the pipe. Directly attach supports to, or directly support them by, a structural member of the skid or foundation. Support from the deck plate or uni-strut clamps is not sufficient. Ensure that piping rests on the support. Avoid gaps between the pipe and support like that shown in Figure 27. Clamps should not be used to pull down the pipe to close such gaps. If necessary, shim under the pipe as needed to eliminate the gap.

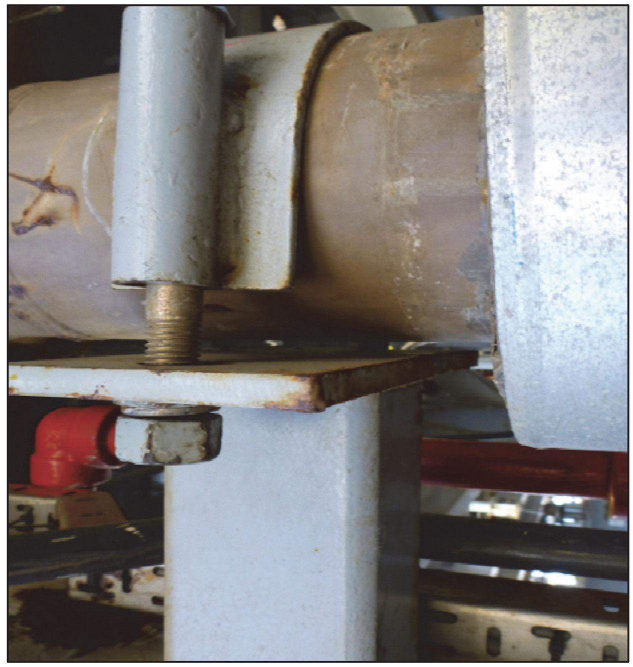

Figure 26: Use I-beams and pipe clamps to support piping. Note round corners for safety.

Figure 27: Piping should rest firmly against supports, using shims under the pipe if necessary.

3.5.3 Inlet Separation

A separator or slug catcher must be installed immediately upstream of the compressor package if any free liquids are contained in the gas stream. The 1st stage scrubbers on compressor packages are designed as a safety device to protect the cylinder from a small amount of condensation from entering the cylinder. They are not intended to be used as the primary method of liquid removal and cannot handle large amounts of liquids. Unless otherwise contractually agreed, end users are expected to provide clean and dry process gas to the compressor.

3.5.4 Suction and Discharge Piping

A full opening block valve should be installed upstream of the compressor as close to the compressor as possible (to minimize the volume of gas released during blow-down). A suction control valve must be used when the upstream pressure can be higher than the rated suction pressure of the compressor. From the aftercooler discharge, a piston type check valve is required, located as close as possible to the compressor. A full opening block valve should be placed in the line downstream of the check valve.

Process gas piping should be sized to ensure adequate suction pressure and volume in the compressor and provide minimum pressure drop through the discharge line into the pipeline. All process gas piping and components should be of working pressures that are equal to or greater than the highest possible pipeline pressure, and they should be protected by properly sized and accurately set pressure relief valves. Threaded suction and discharge connections are discouraged as breakage or loosening may occur due to vibration or settlement. Gas piping should be buried, supported or adequately secured to prevent vibration. An as-built print or sketch of any buried line locations should be made. If present, metering equipment should be a safe distance from the compressor to minimize pulsation and vibration problems.

3.5.5 Starting Bypass

The starting operation of the compressor can be improved by the use of a starting bypass which connects the discharge piping back to the first stage suction. The starting bypass allows the compressor to be started with minimal load on the machine. Without a starting bypass the load must be removed by blowing down the unit to atmospheric pressure, which results in lost or released gas. Many packages have this feature designed into the package, as shown in Figure 28. In Figure 29 blind flanges are present for a recycle system to be added later if needed. In both cases, the starting bypass must be located inside of the suction and discharge block valves. The starting bypass lines are typically small, as shown in Figures 28, and they often are tapped into the discharge ahead of the cooler. In such a case, the bypass is only suitable for operation during startup prior to significant load being applied to the compressor.

Figure 28: Starting bypass line designed into the compressor package.

Figure 29: Provision for starting bypass line to be added later, if needed.

3.5.6 Suction Make-Up (Recycle Valve)

Every compressor package has minimum and maximum suction pressure limits. If the suction pressure drops below the minimum, a low suction switch will shut down the compressor to avoid damage to the unit. A properly installed suction make-up/recycle valve will alleviate this problem by recirculating a portion of the discharge gas volume, adding it back to the suction, "recycling" the gas to maintain the suction pressure above the minimum limit. A suction make-up system, shown in Figure 30 with an on-skid recycle valve, is recommended for larger horsepower units, compressors installed in a booster station, or any unit that is in a critical application. Some compressor stations may have recycle systems installed for the entire station or between the suction and discharge headers as shown in Figure 31, which is a recycle system for two screw compressor packages at a booster station. These types of systems can serve multiple compressors at the station rather than having individual valves for each compressor package. It should be emphasized that although recycle systems are important for helping compressors handle upsets or having to shut down due to low suction pressure, recycling of gas is a very inefficient mode of operation.

Figure 30: An on-skid recycle valve system with automated control valve, connected to the flanges of a starting bypass.

Figure 31: Connection of discharge and suction headers with an automatic valves to provide a recycle system for two screw compressor packages at a booster station.

3.5.7 Starting and Fuel Supply

If the compressor is driven by a natural gas engine (as opposed to an electric motor), it will require a fuel supply with regulated pressure. The compressor packager will provide the specifications for the fuel flow and pressure, e.g., 50 psig, which is a common supply pressure for reciprocating gas engines. In addition to the fuel supply, many packages use a gas or air starter. Supply pressure for gas starters may be as high as 150 psig. Clean starting and fuel gas is critical for reliable operation. Some packages have a single point supply for both starting and fuel gas. On these packages, the fuel is regulated down to a lower pressure as part of the skid piping, as shown in the example in Figure 32.

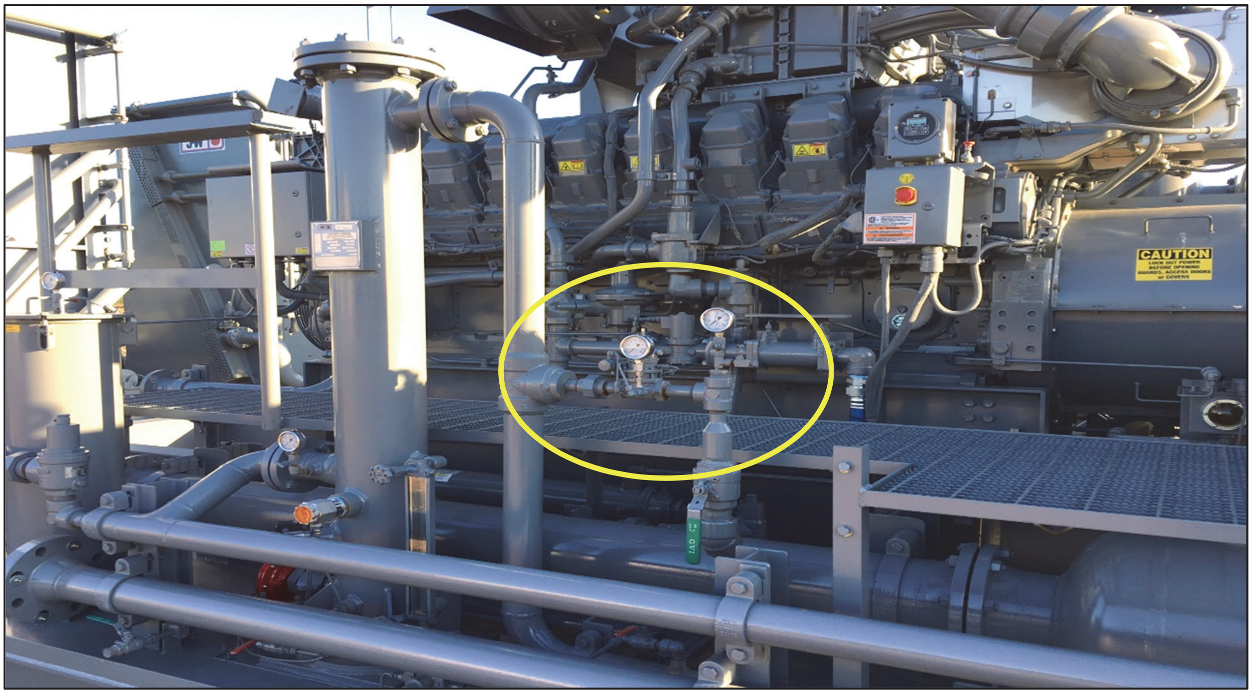

Figure 32: A single-point engine fuel gas and starting supply system.

3.5.8 Vent Lines

Venting is often overlooked as a detailed design exercise, but proper routing and support of the vent lines during installation is critical to proper and safe operation of the compressor package. Well intended vent line routings can become problematic when the execution contributes a local high point that inhibits proper function. It is important to always review and follow equipment manufacturers' recommendations/guidelines for venting. Several suggested practices are provided for reference.

- Avoid tying different vent systems together. Different pressure states can lead to unintended back flows that can have damaging consequences.
- Be cautious of the potential for releasing flammable gases locally around the package. All vents must be piped to a safe atmosphere location or flare. Vent lines must be properly sized and carry a continuous upward slope with no inversions, pulling from all high points in the system.
- Engine crankcase vents, when installed, may have a slight downward slope to a liquid dropout leg. For routings without the dropout leg, hoses should be run with a continuous downward slope to the engine. Crankcase breathers may be relocated, but do not reduce the total number of OEM supplied breathers.
- Avoid any low point liquid traps in vent lines, as these will restrict flow and create back-pressure in the vent line.
- Install a horizontal tee, flapper-type rain cap or other means of protection at the top of vents to mitigate rain or snow from entering, collecting (and potentially freezing) to block the vent line.

- Venting the cooling system is critical to avoid issues with trapped air/vapors that can lead to engine overheating or pump or internal cavitation.
- Vent lines must be adequately supported to avoid vibration, using flex connections where appropriate.
- Starting and pre-lube systems also require venting in most cases.
- In addition to directing gas starter vents to a safe area, both gas and air starter vents must be directed away from personnel areas.
- Conduct a final review of the installation of all vent systems. Check again that there is no potential for venting gas into the immediate area around the package and that high-pressure vents and exhausts are not tied into low-pressure vent systems.

3.5.9 Environmental Rails and Blow Tanks

Many compressor packages are equipped with "environmental" or "ecology" rails that contain any fluids on the skid. Collected fluids are drained off through openings in the skid. Since environmental regulations require all waste fluids be properly disposed of, these skid drains must be connected to a system for capturing and removing the fluids.

Figure 33: Commercially available blow case.

Figure 34: Blow case equipment captures fluids from the compressor skid and transfers them to a larger tank for disposal.

This is especially critical in environmentally sensitive areas, such as near a stream, wetland or body of water. A common solution is the use of a small "blow case" tank. Figure 33 shows a commercially available blow case and Figure 34 shows one mounted near a compressor package in the field. These blow cases can either be manual-type, which requires the operator to physically open and close valves to pressurize the fluid with a small amount of gas taken from the location, and empty the fluids out, or automatic-type, which uses a float and valve system to accomplish the same thing. Waste fluids are typically sent to a larger, above-ground storage tank for temporary storage until collection by a tanker truck. Because liquids drain from the compressor skid to the blow case via gravity, in order to work correctly, the tank must be lower than the top of the skid. Trash and debris can collect on the skid and clog up the drains into the blow tank or interfere with the operation of the blow tank. Routine maintenance should include cleaning of screens or drain openings to prevent clogging.

Safety concerns for blow cases can include a trip hazard if not well-located, and they are a source of gas that must be safely vented, especially for enclosed units. If a package does not contain ecology rails, other options include concrete pads with grating-covered trenches along the side, earthen trenches or containment walls along the sides of the compressor sealed with an impermeable coating or liner. However, the presence of open earthen trenches or walls can present significant trip hazards as well as preventing access to the machine with a service truck or crane.

3.5.10 Lube Oil Supply

An overhead lube oil supply tank is required with most compressor units. These tanks should be piped with ¾ in. or larger rigid pipe and set far enough away from the unit so that it will not interfere with servicing the unit. For colder ambient applications, see Section 3.7.

3.5.11 Antifreeze/Coolant Supply

If the compressor arrives without coolant, the initial fill should be made with water which allows any leaks to be repaired without waste of expensive coolants. As soon as possible after initial start-up, the water should be drained and replaced with a commonly available premixed antifreeze/glycol solution.

3.6 Buildings and Shelters

When field compressors are enclosed, tight clearances and obstructions can pose significant safety issues. Safe access and egress require that there be a clear path around the unit, both for routine service and in the event of an emergency. An adequate number of emergency exits must be provided, as required by OSHA[8] Subpart E.

Compressor service and maintenance often necessitates the use of a service truck and/or a crane. Whenever possible, buildings or shelters should be provided with monorail or bridge cranes with suitable capacity and clearance to handle the heaviest piece of removable equipment in the building. When adequate cranes cannot be provided in the building or shelter, sufficient means of access must be provided for portable cranes or service trucks with cranes and for safely handling and moving heavy components into and out of the building. Installing overhead doors with a concrete apron is best practice for this purpose.

Adequate ventilation is required for any compressor package installed in a building or enclosure. Fresh air must be consistently provided through an acceptable means. Engine exhaust gases are toxic, and must be safely delivered outside of the enclosure or building at all times.

Avoid the storage of unnecessary combustible materials inside a compressor package enclosure. If it is necessary to store compressor and engine lube oils and coolants inside, they must be stored in proper containers, meeting applicable OSHA and NFPA standards, and located a safe distance from any ignition source.

For fully enclosed compressor packages, all vents must be piped outside. As these are typically higher with long pipe lengths, vent stacks must be securely braced. When delivering to atmosphere, they must be of sufficient height to completely clear the roof of the building, without allowing natural air currents to blow gas back inside the building.

Ensure that the correct hazard classification is specified and implemented for all electrical systems and follow NEC/NFPA70[6].

Fixed monitoring and alarm systems may be required for flammable gas and/or sour gas.

Operators are encouraged to investigate before-hand any applicable laws and permitting regulations that apply to where a compressor building will be located. For example, Colorado Resolution 35[7] regulates non-residential and industrial structures.

Sections 10 and 12 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] provide more information and detailed guidance on compressor package buildings, enclosures and electrical systems.

3.7 Cold Weather Considerations

When ambient temperatures are below 40˚F at a field gas compressor location, numerous practices must be followed. It is important that these practices are considered in the design, fabrication, installation and operation of the compressor package.

1. Oil feed lines should be 2 in. or larger in diameter, heat traced and insulated to ensure continuous flow. In some cases, oil tanks must be heated and insulated as well.
2. The lowest ambient temperature allowed should be determined and clearly communicated, as well as the maximum ambient. The compressor package and installation must be compatible with safe operation over the entire range of ambient temperatures, or provisions must be made for preventing start-up, limiting operation, or ceasing operation, as appropriate, when ambient conditions are outside the reasonable and safe operating range.
3. Without compromising safety, the site design should be laid out to minimize distances between the air system, lubrication and coolant supply systems, coolers, scrubbers, and other auxiliaries to the engine and compressor package.
4. Off-skid drains to waste fluids tank may have to be heat traced for proper operation.
5. Drain lines should be larger to ensure drainage, at least 1 ½ times larger diameter than lines seeing normal ambient temperatures.
6. Engine fuel gas pressure cuts should be made away from the engine. Where this is impractical, the fuel gas line should be heat traced and insulated, both before and after the pressure regulator, to prevent the formation and collection of liquid in the fuel lines.
7. Engine and compressor lube oil fill lines should be at least 2 in. nominal pipe size for quick filling of crankcases.
8. Hot start systems should be provided, sized appropriately for system oil volume(s). In cold climates, hot start systems should be automatically activated upon shut down, and should not be turned off until package startup is achieved. In other applications, the hot start should be controlled by the crankcase oil temperature, so that startup is not initiated until oil temperature has reached at least 60˚F.
9. In some cases, jacket coolant heaters may be recommended, rather than oil heaters, for the unit to achieve a proper start.
10. Compressor lubricator box supply lines and oil supply tanks should be heat taped and insulated to ensure a continuous supply of oil to the lubricator pumps. If the lubricators are fed from the compressor crankcase, this requirement should not be necessary.
11. OEM specified engine and compressor coolant and lube oil temperature minimums for starting and loading should be programmed into the control system to prevent starting and early loading of a cold unit. Consult the engine and compressor manufacturers' specifications for guidance. For repackaged or reapplied older equipment that may not be supported by an OEM, following are typical requirements:
    - Typical start-up permissives: Compressor oil temperature of at least 50˚F and engine oil temperature of at least 50˚F.

- Typical load permissives: Compressor oil temperature of at least 95˚F, engine oil temperature of at least 125˚F, engine jacket water temperature of at least 165˚F, and engine auxiliary water temperature of at least 120˚F.

12. Air inlet filters should be sized and designed for colder ambient temperatures to prevent filter icing and snow ingestion.
13. If a package is installed in a building with air filters mounted outside, the intake air ducting should be sloped downward from the engine to the filters to prevent any ice formation in the piping of an idle unit.
14. In cold climates, units requiring catalytic converters may require that the exhaust piping be insulated to keep the exhaust temperature high enough for the converter to achieve efficient conversion.
15. Avoid the use of PVC as a material in cold climates for crankcase ventilation systems due to brittleness.
16. Engine air start systems should be sized based on the higher torque loads required for starting a cold engine with colder oil than normal applications. Likewise, the starting air system should be upgraded to provide larger receiver capacity and larger diameter pipe to supply sufficient flow to the starters.
17. Engine inlet air temperatures should be consistent with permissible startup and operation specifications per OEM guidelines. Cooler louver controls and coolant temperature regulation should be employed to regulate the post turbocharger air temperature supplied to the engine for combustion.
18. Coolers should have automatic temperature control of the cooler louvers to control coolant and gas temperatures. In extreme cold ambient temperatures, a cooler air recirculation system, or variable speed fan drive may also be required.
19. A thermodynamic review of the gas at the various operating conditions through the compression and cooling stages throughout the system is advisable when operating in cold ambient conditions. Where there is a risk of hydrate formation, coolers should be supplied with a methanol injection port in the gas piping upstream of the cooler coils.
20. Coolers should be designed for a 50% glycol/water mixture.
21. Hail guards should be supplied on coolers.
22. Design temperatures below -20˚F will require special materials and welding procedures.
23. Scrubber bridles and drains should be heat traced and insulated. No-freeze type dump valves must be used.
24. Scrubber piping should be designed so that there are no low spots between the package inlet scrubber and the compressor and between the station scrubber and the package.
25. Control panels may require heaters. Consideration for this should be based on the control system's minimum operation temperature. Many PLC-based systems cannot handle subfreezing temperatures.
26. Unless exempted by ASME code[2], Charpy impact tests should be required on all pressurized equipment operating at -20˚F to -50˚F. Grade B carbon steel may be used to a temperature of -155˚F without Charpy testing, provided the maximum operating pressure does not exceed 0.3 times the rated system design pressure. Otherwise, stainless steel should be used when pressurized components are operating at, or exposed to, temperatures lower than -50˚F.
27. Consider Arctic packages for colder climates, i.e., ambient temperatures of less than about 40˚F. As shown in the examples in Figures 35 and 36, these packages are based on a wider skid, which includes an enclosure around the complete package in lieu of placing the unit in a dedicated building. These packages are self-contained, but care should be taken to insure that routine maintenance can be performed, and that the outer walls and roof can be removed when more extensive work is required.

Figure 35: Consider an enclosed or Artic package for sites having ambients below 40˚F.

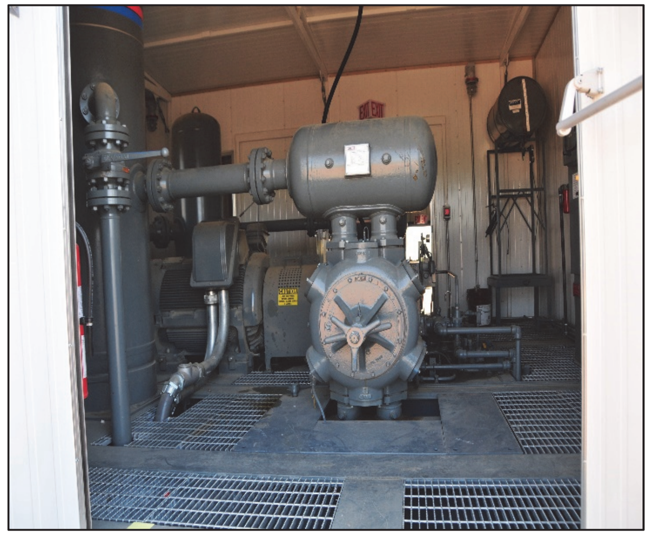

Figure 36: Enclosed packages must have space for performing routine maintenance.

4. Start Up and Commissioning

The start up and commissioning of leased compressor packages should be conducted only by the Compressor Leasing Company. If the compressor package has been purchased directly by the end user from a packager, the start up and commissioning should be conducted by that packager or its authorized designee. Section 14.3.8 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] provides additional detailed guidance for commissioning.

5. Operation

Although Section 15 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[5] provides more extensive coverage of operation and maintenance considerations for compressor packages, there are a number of important considerations that operators must be fully aware of in the initial installation, commissioning and operational phases. A number of those considerations are discussed herein.

Compressor package operators must always be clearly aware that the machine is handling a highly flammable substance – natural gas, and as long as the natural gas is not allowed to mix with air, it is relatively incombustible. However, if air is allowed into the system, there is the risk of an explosion. Any gas (air or natural gas) flows from a higher pressure zone to any lower pressure area zone. Therefore, any time the pressure in the gas system (i.e., compressor cylinders, piping, bypass/vent piping, scrubbers, separators and pulsation bottles) is lower than atmospheric pressure, air will be pulled into the compressor system through vents or other openings. It is therefore important to ensure that all possible points of air entry into the natural gas systems – process, fuel or starting - are closed when the internal pressure is near atmospheric pressure.

5.1 General Safety

Refer to the safety guidelines provided in Section 2.

5.2 Compressor System Purging

The entire compressor system must be fully purged of all air before start-up, and positive-pressure maintained on the complete system at all times while starting, idling and running. Two examples of procedures are presented herein for guidance on purging. These are only basic procedures, intended as generalized learning tools for field gas compressor operators. There are many different variations of gas compressor packages, and many different ways to connect them to the pipeline system. Appropriate resources should be consulted for the correct procedure for the specific machine.

Compressor Package Purging – Example 1. The following is from the Enform Gas Operators' Course[3].

- Open the vent valve(s)
- Close the recycle valve.
- Crack open the suction valve. Gas will flow through the compressor and out the vent line.
- Allow purge to continue for at least 30 seconds, preferably one minute. At the end of this time, open the recycle line to purge any air that may be trapped in it.
- If there is no check valve in the discharge piping, crack the discharge valve and purge air from the outer end of the discharge line. Omit this step if the discharge line has a check valve.
- Close the vent valve.
- Ensure the valve in the recycle line is open and valves in the suction and discharge lines are closed. The discharge valve can be open if a check valve is present. Depending upon the port size in the recycle valve and the design of the machine, the suction valves may also be left open.
- Valve operation in the recycle line is important to safely start up a compressor. The valve in the recycle line must always be open when a compressor is started. If the valve is closed when the compressor starts running, it will pull a vacuum on the suction piping, and may pull air into the system, creating a dangerous situation.
- Next, the driver is started. Once it gets up to operating speed, the compressor can be put into service. Follow this procedure:
  - Open the valve in the discharge line (if left closed)
  - Slowly open the valve in the suction line (if left closed).
  - Slowly close the valve in the recycle line.
- In some applications, compressor units have several cylinders in different services, or in second- or third-stage compression service. The order of putting each cylinder in service is not important if the cylinders are in different services. Generally, cylinders requiring the least power are put in service first, and cylinders requiring the most power are put in service last.
- If the unit has two or more stages of compression (i.e., discharge from one or more cylinders enters the suction of other cylinders), the highest-compression stage cylinders are put in service first and the lowest compression stage is put in service last. There will be no place for the discharge gas to go if the first stage cylinders are put in service first (discharge gas normally flows to the second stage cylinders but they would not be in service yet). Discharge pressure from the first stage will rise and open the relief valve on the discharge line, allowing gas to flow out a vent stack into the air. This not only wastes gas, but may also result in a leaking relief valve, as they often fail to seat after opening.

Compressor Package Purging – Example 2. The following is a procedure provided in previous GCA guidelines[4].

- Purge unit before restarting or if gas system has been opened up to the atmosphere.
- Close suction block valve.
- Close discharge block valve.
- Open the bypass valve.
- Open the blow down valve.
- Open the suction valve allowing gas to blow out of the blow down line.

- Close the bypass valve, making sure at this point gas is still blowing out the blow down line.
- Open discharge block valve.
- Close the blow down valve, at this point the system should be purged.
- Open bypass valve and the unit should be ready to start.

5.3 Alarm and Shutdown Devices

Compressor packages are equipped with a multitude of alarm and shutdown devices. These may range from a simple analog device that is hard wired to a safety panel to a device that is integrated with a complex PLC system. These devices are designed to protect the equipment and personnel by ensuring that the equipment is operated within its design envelope. Some devices have a fixed set point while others can be adjusted based on the operation of the equipment. For example, a package may have a shutdown for low oil pressure on the engine. This is generally fixed at a value that is specified for the particular make and model of the engine. Fixed shutdown set points are generally not adjustable by the operator. However, there may be some devices that are adjustable. One example would be the switch gauge shown in Figure 37, which includes high or low pressure shutdowns.

Figure 37: A pressure gauge with high and low safety trip points.

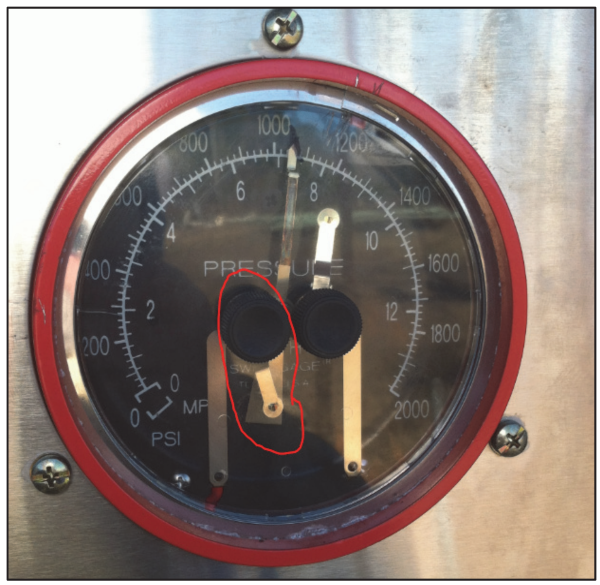

Figure 38: A pressure gauge with low pressure safety trip disabled.

The set points are determined by the safe operating range of that particular process stream, e.g., 2nd inter-stage pressure in Figure 37. The limit may be determined by something obvious like a maximum allowable working pressure (MAWP), or it may be determined by something more inconspicuous, such as a pressure that will cause rod load to be exceeded. In any case, it is the responsibility of the operator to know the limits and to maintain the safety shutdowns at those limits. Shutdowns or safety trips should not be adjusted without evaluating the possible effects, and shutdowns should never be disabled or by-passed. If a safety shutdown is repeatedly shutting down a compressor, then the cause (whether a malfunctioning sensing device or an actual process limit being exceeded) must be determined and rectified before restarting and operating the compressor package. Figure 38 shows a discharge pressure gauge where the low pressure trip switch has been rolled down past zero, thus disabling this shutdown device. This is an unsafe practice that puts equipment and personnel at risk.

Depending on the application, fire safety valves, which fail closed when triggered by heat, may also be needed on a field gas compressor. The best way to determine this is through a proper hazard analysis.

Some packages may already be equipped with these, while others may need them added later. These safety shutdown devices can interrupt the flow of oil, coolant, and gas in a serious fire, thus improving the level of safety and protecting equipment from more serious damage. Figure 39 shows a fire safety valve installed for an engine oil meter and controller.

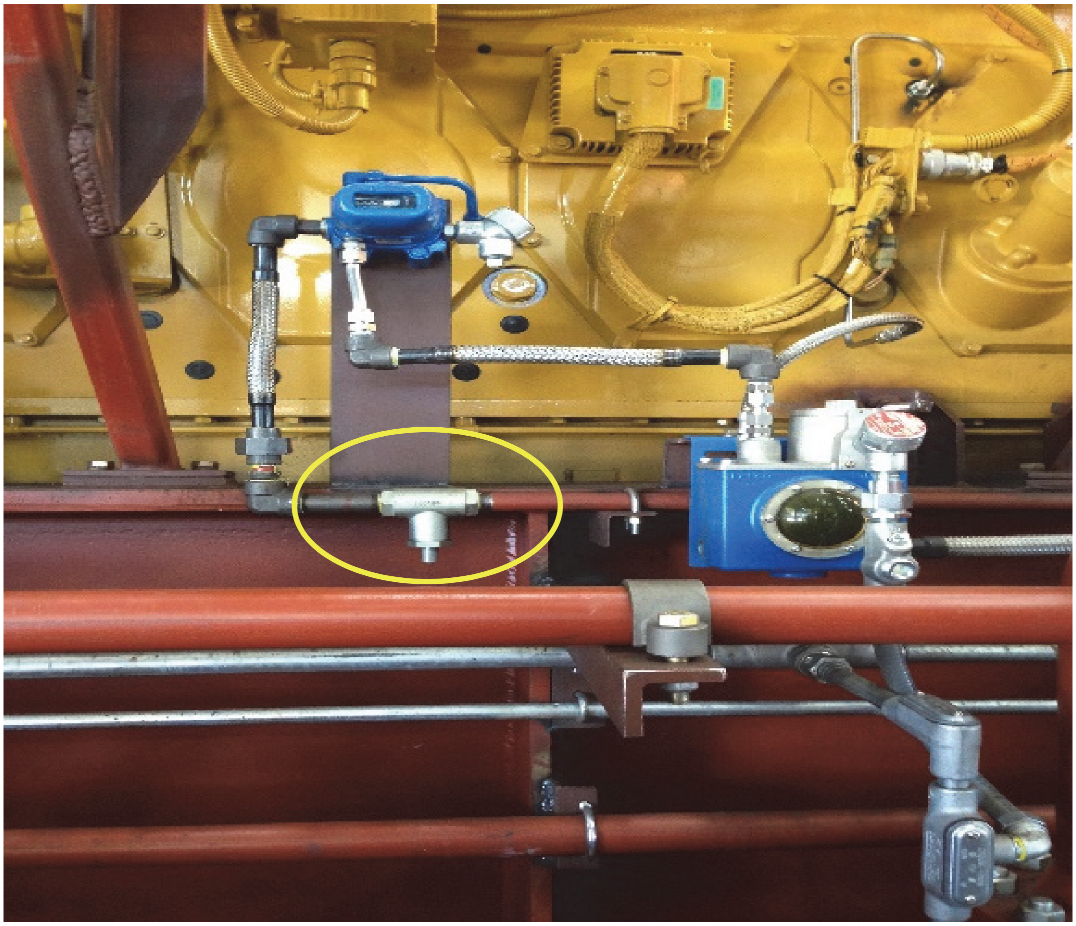

Figure 39: A fire safety valve installed to stop engine oil flow during a thermal event.

5.4 Machine Guards and Covers

Rotating machine parts have the potential to cause severe workplace injuries or death. Injuries can include lacerations, crushed fingers or hands, amputations, burns, or blindness. Machine guards are designed to protect personnel from the hazards of moving equipment. Most guards are designed to be lighter than 50 lb. and removable, to more easily allow for maintenance on the equipment when necessary. However, the compressor package should never be operated without the guards in place. Therefore, anytime a guard is removed, the proper Log Out / Tag Out procedures should be followed to prevent movement of the equipment while the guard is removed. Machine guards must also be maintained in good condition. Vibration and corrosion can deteriorate guards or the fastening systems that keep them in place, rendering the guard ineffective.

5.5 Expectations of Operators

Basic training and qualification are fundamental requirements for operators. Although requirements will vary from company to company and application to application, there are several fundamental expectations of compressor package operators. Depending on the level and type of instrumentation, these may be done from a central console, at a local panel or distributed around the compressor package.

1. Monitor meters and pressure gauges to determine consumption rate variations, temperatures, and pressures.
2. Adjust valves and equipment to obtain specified performance.
3. Operate power-driven pumps and/or compressors that transfer liquids, semi-liquids, and gases.
4. Record instrument readings and operational changes in operating logs.
5. Move controls and turn valves to start compressors, engines, pumps, and auxiliary equipment.
6. Respond to problems by adjusting control room or control panel equipment, and/or instructing other personnel to adjust equipment at problem locations or in other control areas.
7. Take samples of gases and conduct chemical tests in order to determine gas quality and sulfur or moisture content, or send samples to laboratories for analysis.
8. Clean, lubricate, and adjust equipment, and replace filters and gaskets, using hand tools.

The equipment manufacturer's documentation typically includes guidance for start-up and operation. This information is intended to help the operator tailor their practices to maximize performance, safety and availability of the equipment. Following is a list of additional important considerations for operators.

1. Regular walk-around inspections find issues before they cause problems (leaks; guards not in place; loose fasteners, mounting brackets and clamps; damaged wiring, etc.)
2. Special configurations, accessories, checklists or guidelines often may be needed to optimize the equipment for the special considerations of the site, including, but not limited to:
   - Jacket water and lube oil heaters for cold climates
   - Configurations for sour gas
   - Start-up checklists to help avoid missing a critical step
   - Purge cycle cranking after hot shutdown or failed start attempt
   - Warm-up period for larger equipment prior to loading
   - Operating guidelines help to achieve targeted maintenance intervals
   - Minimum loading criteria indicate how to maintain proper engine oil control, avoiding rapid deposit buildup that can force more frequent servicing
   - Recommended cooldown/shutdown procedures to reduce stress on critical components. (Avoid using the emergency stop for a normal shutdown.)
   - Automated controls can make these processes more robust/repeatable

5.6 Expectations of Maintenance Personnel

Basic training and qualification are fundamental requirements for maintenance personnel, including OEM training for engines and compressors. Although requirements will vary from company to company and application to application, there are several fundamental expectations of compressor package maintenance personnel.

1. Conduct preventive and corrective field mechanical service on engines, motors, compressors, air-coolers, and associated equipment and controls.
2. Perform scheduled and unscheduled equipment repairs and maintenance.
3. Diagnose and repair mechanical problems on separators, inlet scrubbers, dehydrators, line heaters, pumps, and all associated controls.
4. Possess/develop and maintain comprehensive mechanical, diagnostics, and analytical skills.
5. Respond to emergency maintenance calls.
6. Submit accurate maintenance reports and other necessary paperwork.

5.7 Additional Operating and Maintenance Considerations

Several other important considerations for the operation and maintenance of high-speed reciprocating and rotary screw compressor packages are listed herein.

1. Periodically verify that all relief valve settings and tags comply with design specifications. The frequency of inspection and testing can depend on requirements established by regulatory bodies, manufacturer's recommendations, and process conditions. Typically, this is performed on an annual basis not to exceed 15 months intervals. However, it is important to note that the interval of a relief valve in a corrosive service would be shorter than the interval required for the same relief valve in a clean, noncorrosive service.
2. Periodically check all temperature and pressure transmitter settings and calibration records, including all alarms and shutdowns. Make sure that they comply with manufacturer's specifications and control system documentation. For best protection, set discharge temperature limits at 10% above normal operation, not at the maximum permitted.
3. Whenever the coolant system is opened, make sure that the coolant systems are completely filled and completely purged of air to prevent hot spots that can lead to overheating and cavitation damage.
4. Follow system cleanliness guidelines whenever equipment or systems are opened for maintenance.
5. Keep adjustable alignment chocks clean and avoid exposure to rain which can cause them to rust and bind up.
6. Follow manufacturer's specifications for lubricating oil and coolant.
7. Ensure that new operators and maintenance personnel receive the appropriate manufacturer's training prior to assigning them important responsibilities.
8. Begin taking engine and compressor oil samples as soon as practical (generally within the first 500 to 1000 hours) after initially starting the unit, and continue sampling at regular intervals as recommended by the equipment manufacturers. Take samples only from flowing lines, avoiding sampling from dead legs of piping or stagnant sumps. Use a competent lab for oil testing and act promptly in response to indications of oil degradation or significant metal content that would indicate equipment wear.
9. Similarly, coolant samples should be taken at regular intervals in accordance with the coolant manufacturer's recommendations.
10. Periodically check foundation bolts, guide supports, cylinder supports, bottle supports and piping clamps for tightness. If loosening occurs, investigate and remedy the cause before retightening. Any loosening of foundation, guide or cylinder supports may also require that crankshaft deflection, rod run-out or cross-head clearances be rechecked.
11. Regularly inspect the package for any signs of vibration, especially looking at bolting, tubing lines, small bore piping, conduit, and instrumentation.
12. Although elastomeric couplings are not commonly applied on field gas compressor package, when they are it is important to recognize that experience has shown that they require periodic replacement of parts (can be based on time in operation and time since manufacture). Spares for elastomeric couplings should be stocked for immediate replacement. Elastomers are sensitive to petrochemicals, heat, etc. Elastomeric couplings can overheat and melt, resulting in a loss of torsional damping and ultimately, a loss of connection to the driven equipment.
13. Routine maintenance spares should be stocked within reasonable distance of the compressor facility. Replacement parts for custom electric motors, custom compressors, special couplings, non-standard controls, and equipment not made within the U.S. may have long lead times. Consideration should be given to stocking these items or reaching a stocking agreement with the manufacturers that meets the end user's turnaround needs.

6. References

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6. National Fire Protection Association, NEC/*NFPA 70, National Electrical Code*, 2017.
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