



Property Risk Consulting Guidelines

XL Risk Consulting

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PREVENTION OF EXPLOSION AND FIRE IN COMPRESSED AIR VESSELS AND SYSTEMS

INTRODUCTION

Most compressed air systems by nature contain all the elements necessary for fire or explosion, namely oxygen from the air, fuel from the compressor lubricating system, and heat from the process of compression. Mineral oils typically used for lubrication may have an autoignition temperature 250°F (140°C) lower than that at atmospheric conditions. It is helpful to limit the amount of fuel available should ignition occur by keeping the air system clean and by carefully controlling the lubricating system; however, it is not normally possible to entirely eliminate combustibles from the system. Accordingly, the key to preventing loss is to prevent ignition.

Three types of systems will be considered:

- Utility systems with reciprocating compressors.
- Systems with oil-flooded rotary compressors.
- High pressure systems (250 psi [17.2 bar] or greater).

Utility systems are those which use lubricated compressors and which do not employ extensive purification of the air stream before distribution. These include “shop” air systems, most pneumatic or air/hydraulic systems, and some instrument air systems.

This material is specific to fire and explosion prevention in compressed air systems and does not cover all of the instrumentation, protective device, and maintenance needs of air systems, vessels and compressors, nor does it deal with systems involving oxygen or other gases. External fire protection is not addressed.

POSITION

Any review of installed compressed air systems and their maintenance programs should address the following:

- The system and its components must be balanced and sized to meet the demand. Overloaded compressors and coolers are likely to pass excessive amounts of lubricant and, in many cases, will overheat.
- Provide compressed air systems for cooling of compressed air after each stage of compression, as soon as is practicable after the compression takes place.
- Install temperature instruments to monitor the performance of the compressor and its cooling equipment. Alarms and protective features should be provided for all compressors, but are not

- required except for compressors larger than 25 hp (18.5 kW). As a minimum, provide a high temperature alarm and compressor shutdown which senses the final-stage discharge temperature. Discharge temperatures should never be permitted to exceed 300°F (150°C).
- When water cooling is used, install a flow switch located within the bounds of the water isolation valves. Interlock the flow switch with the prime mover to verify cooling water flow before and during compressor operation.
 - Compressor and air system maintenance should prevent the accumulation of either excess lubricant or carbon deposits, and to prevent the development of conditions which cause excessively high temperatures. The maintenance program should include recording of temperatures and other selected parameters in a log or other data collection and retention system.
 - Where possible, compressors should be covered by a vibration monitoring program. While vibration monitoring has many advantages beyond fire and explosion prevention, many types of failure which are detected at an early stage by this technique may result in overheating if not corrected.
 - Pipe the safety valve discharge connections to a safe discharge point. For oil-flooded components, such as rotary compression oil separators, this discharge point must be outside.
 - Additional precautions, noted later, will be required for systems using high-pressure air, which is generally considered to be 250 psi (17.2 bar) or greater.

DISCUSSION

Compressed air system internal fires and explosions typically share these characteristics:

- They are totally unexpected. Compressed air systems tend to be seen as utility services no more worthy of concern than domestic water systems.
- Although they can be spectacular, they frequently cause little damage outside the system. Unfortunately, since most plants are 100% dependent on compressed air, even well-contained fires can produce substantial time element losses.
- They are highly preventable. Minimal attention to the factors which produce the hazards can substantially mitigate them.
- Most losses are the result of combustion of lubricating oil or its carbonaceous degradation products (“coke”), both of which accumulate as an internal film or coating in system components downstream of the compressor.

The most likely explosion initiating mechanisms involve combustion of deposits rather than direct ignition of a combustible oil/air mixture. Current research suggests the following:

- Peroxides, which can decompose with incandescence at 330°F (165°C), may form in carbon deposits.
- Peroxide formation has been demonstrated at 100 psi (6.9 bar). The reaction may be catalyzed by iron oxides.
- The shock produced by ignition of deposits can dislodge other deposits, producing an explosive mixture. A series of explosions may then travel through an entire system.
- At 200 psi (13.8 bar), the auto ignition temperature of the oil may be as low as 414°F (212°C).

An explosive mixture is unlikely at the pressures encountered in utility air systems because of the large volume and flow rate. The mixture is normally too lean in reciprocating compressor systems and too rich in most parts of oil-flooded rotary compressor systems upstream of the separator. Explosive mixtures are only associated with compressor oil seal failures or with high-pressure systems. Although highly improbable, it is also possible to obtain an explosive mixture in any system by ingestion of flammable vapors due to poor location of the suction inlet.

A possible solution is the use of synthetic lubricants or blended lubricants as a substitute for the traditional mineral-oil-based lubricants. While these oils will typically have autoignition temperatures approximately 50% higher than comparable mineral oils, and in most cases either do not carbonize or do so more slowly, they are not a panacea.

If a new system is designed to use synthetic lubricants or blends, a combustion-resistant and relatively trouble-free installation is likely if appropriate maintenance is performed. For retrofits, the following items require consideration:

- Synthetics are in general far more expensive to purchase than mineral oils, however, they frequently last longer. While they may be superior in many ways, it is important that those considering a change to a synthetic lubricant confirm the lubricating qualities of the proposed fluid on a point-by-point basis with the equipment manufacturer's specifications.
- The solvent action of the synthetic lubricant may differ significantly from the mineral oil it replaces. This can result in large-scale movement of debris in the system, resulting in clogging or other damage to downstream equipment. Also, paint both inside and outside the system may be damaged.
- The entire system must be examined for seals and gaskets which may not be compatible with the new fluid. This is an insidious problem, because a given lubricant may shrink, swell or simply destroy one type of "rubber" gasket and have no effect on an identical-looking one. The matter is further complicated by the fact that it may not be possible to identify all the materials used for sealing over the years, especially in older systems.

For mineral-oil systems, available research suggests that carbon deposits are minimized by oils of low viscosity, naphthalene base and narrow distillation range. Any replacement of lubricating fluids should be approached cautiously.

Regardless of the type of lubricant employed, cautions in the control of application and in the removal of excess oil are necessary. In many large reciprocating compressors, cylinder lubrication is still performed by a Manzel Lubricator, or an equivalent device, which applies the lubricant on a drops-per-minute basis. More accurate precision lubrication systems are now available and their use is suggested.

With any type of system, the manufacturer's recommended lubrication rate is a starting point, with the actual required rate only being determined by examination of the coating of oil in the cylinder after a period of operation. It is likely that different cylinders on a machine will require different feed rates.

Since a certain amount of oil will inevitably become entrained in the air stream, means to remove excess oil are needed. Removal is usually accomplished by traps or centrifugal separators located downstream of the various system coolers. Mist eliminators may be helpful in some applications. If a significant amount of oil is found in the system air receiver, an examination needs to be made for excessive lubrication or deficient oil removal. At the same time, caution should be exercised, because under-lubrication will quickly result in other damage to the compressors.

A rigorous program for system cleanliness is important. It is possible to clean an air system which has become fouled with oil or carbonaceous deposits, however, it is an expensive and time-consuming task, often of questionable efficacy.

If system cleanup is necessary, the choice of technique must be based on the following:

- Low points, changes in diameter and in direction, and most valves and fittings will require attention not only to insure they are cleaned but that they do not accumulate deposits loosened from elsewhere in the system.
- The cleaning medium must not create a hazard. Solvents may be effective cleaning agents, but any solvent residues could be more dangerous than the original problem. Caustic or acidic washes or even water or steam may have a corrosive effect on system components. Any liquid left in the system will result in hammering or other damage to the system or the equipment served.

- The use of air driven pigs or tools is extremely dangerous and is not recommended. Development of an explosive mixture is almost inevitable.

If cleaning is necessary, the services of a firm specializing in this activity are recommended.

Utility Systems, Reciprocating Compressors

Although there is a considerable trend toward rotary and centrifugal machines, reciprocating compressors still dominate. The most common compressed air system combustion events involve ignition of compressor lubricating oil and products of its decomposition which have accumulated at the discharge, with possibly explosive results in downstream valves, piping or vessels. The source of ignition is one or more of the following:

- Excess carbon or carbonaceous deposits in the downstream piping — Such deposits are the result of cracking or breakdown of the lubricating oil due to the heat of compression and/or of oxidation of oil deposits. While the actual mechanism of ignition of these deposits is not fully agreed upon, large amounts of hard and porous deposits are usually found in systems which have had difficulty.
- Recompression of air — Whether caused by worn or damaged valves, or by blowback in double-acting cylinders, leakage of compressed air back into the active portion of the cylinder will result in an increase in air temperature. In extreme cases, valves have actually melted due to this effect.
- Loss of cooling — Compressing air is a polytropic process; accordingly, if safe and usable compressor discharge temperatures are to be attained, heat must be removed from the cylinders and from the air after each stage of compression. Insufficient cooling capacity, or capacity lost due to fouling of heat exchange surfaces or loss of flow of the cooling medium, may result in temperatures high enough to cause ignition.

Instrumentation and maintenance of the cooling system should be examined. Most reciprocating air compressors will have water-cooled cylinders, inter-stage coolers (intercoolers) and after coolers. Some will also have oil coolers. A flow switch interlock should be provided to verify cooling water flow before the machine is started and to shut down the machine if flow is subsequently lost.

Thermometers should be provided for both the water and air or oil inlet and outlet temperatures. These temperatures should be regularly noted and recorded. The recommended frequency is daily for units up to 25 hp (18.5 kW), each shift for units up to 100 hp (75 kW) and hourly for larger units. Logs should be reviewed periodically for adverse trends.

The crucial trends to be monitored are increases in outlet temperature for a given inlet temperature. Analysis of such changes may indicate machine distress resulting in increased heat loading of the cooler or may reveal fouling of the heat exchanger surfaces. Compressors and coolers which have frequent fouling problems may require treated cooling water.

At minimum, the compressor final stage discharge and the after cooler discharge should be provided with a high temperature alarm and preferably a high temperature shutdown. An automatic shutdown should also be provided for loss of lubrication and for loss of cooling water flow.

Finally, the maintenance of the machine itself needs to be considered. In general, valves should be inspected at least twice annually or every 5000 hours. The machine should be overhauled at least annually or every 10,000 hours. While these intervals may be increased with experience, such increase is warranted only when the overall condition of the machine is carefully monitored and analyzed.

Infrared examination may serve to monitor the condition of compressor valves. Vibration monitoring may be helpful for evaluating the overall machine condition, however, with low speed machines in general and reciprocating machines in particular, the technique is complicated by the frequencies and noise levels endemic to the machine.

Oil-Flooded Rotary Compressors

The principal hazard for oil-flooded rotary compressors is fire. These compressors operate with the rotors or “screws” in an oil bath. This results in a large amount of oil being mixed with the air stream at the discharge. Accordingly, such machines are provided with a separator connected directly to the machine. The separator must not only remove the oil from the air, but return the oil to the compressor, normally by way of a cooler.

With a rich source of fuel available at the hottest point in the system, any event which can provide a source of ignition will result in an internal fire. Since internal fire will normally lift the safety valve, a torch effect may result in spread of the fire to the surroundings. Even without an internal fire, oil separator safety valves may discharge an explosively flammable air-oil mist. Therefore, oil separator safety valve discharge connections must be piped to a safe outdoor location.

The events most commonly resulting in fires in rotary compressors are these:

- **Loss of cooling** - Fouling of the oil cooler or loss of cooling water flow will result in a temperature rise. If this condition is left unchecked, it will cause ignition either by damage to the oil, breakdown of the oil film on the rotors, excess temperature buildup due to the heat of compression, or a combination of these. Accordingly, rotary compressors should have alarm and shutdown functions for loss of cooling water flow and high discharge temperature. Paradoxically, rotary compressors can be over-cooled. If operated at too low a temperature, internal condensation is possible, which can result in corrosion and excess friction.
- **Bearing failure** - Excess wear or damage to the compressor bearings may directly generate excess heat, resulting in combustion, or it may cause interference between the rotors, resulting in frictional heat. In either case, installed high temperature shutdown devices may not respond until a fire has already started. The best defence against these events is general machine maintenance which, in addition to the manufacturer’s recommended overhauls and inspections, involves monitoring the machine with “trained ears” and preferably by periodic vibration monitoring or an installed vibration monitor.
- **Overload** - Rotary compressors are designed to discharge to a specific head. Overload of the machine, e.g., operation against too low a back pressure, may result in lubrication failure or cooling system overload.

Cooling system maintenance should be performed as previously suggested for reciprocating compressors. General maintenance should be in accordance with the manufacturer’s recommendations. Inspection of internal parts at intervals greater than 10,000 hours should be approached with extreme caution. Vibration monitoring is an effective technique for tracking the internal condition of most rotary machines.

High-Pressure (250 psi [17.2 bar]) Systems

While high-pressure air systems are subject to the proceeding comments, the principal hazard is represented by compression-ignition or “diesel” explosions. Design and operation of the system and operator awareness of the hazard are critical to safe operation.

The following points should be considered when evaluating such systems:

- The compressor should start fully unloaded, to avoid undue stress on the drive line and to prevent damage which would result from attempting to compress condensate or other fluid that may accumulate in the cylinders.
- Provision should be made to ensure that any excess oil is removed from the cylinders before they are loaded. Compression ratios in high-pressure air compressors may be high enough to result in compression-ignition or “dieseling.”
- Loading should progress in sequential fashion from low to high stages to avoid sudden pressure increases and imbalances that may otherwise result.
- The system must be maintained in a scrupulously clean condition with regard to oil accumulation, because oil in a high-pressure air system is subject to compression-ignition if a

sudden pressure change occurs. The system internals must be periodically inspected and cleaned if necessary.

- Quick-opening valves are to be avoided, because sudden introduction of high-pressure air may result in heating of the piping and ignition of any oils that may be present. If such devices are employed, care must be taken that they never serve to admit high-pressure air to a short dead-ended section of piping or other limited volume, since these may rupture or become hot enough to ignite their surroundings, even if no oil is present.
- Operating procedures should specify a cautious approach to manually operated valves, to insure slow buildup of pressure in downstream systems. The temperature rise associated with pressurizing a pipe section or component is a strong function of the rate of pressure increase.

The compressor manufacturer and system installer should provide additional precautions for each installation.