

# How to limit fire and explosion hazards with oil-flooded rotary screw compressors

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## Introduction

From 1973 through 1986, a total of 12 fires involving oil-flooded rotary screw compressors (OFRSC) were reported to the Mine Safety and Health Administration (MSHA). Most of these incidents were attributed to faulty or bypassed safeguards, or improper maintenance. The cause of a fire in an OFRSC is unique when compared to other types of compressors.

A compressor inspection checklist is provided here that can be referenced when conducting regularly scheduled maintenance operations. This checklist and a well-planned program of periodic training and maintenance should help minimize the probability of fires and explosions in OFRSC's.

## Operation

A rotary screw compressor operates on the principle of positive displacement of air. Compressed air in this type of compressor is produced by the meshing of two helical rotors, or screws, as they rotate within a steel housing called a stator.

The male rotor normally has four lobes and is driven either directly or indirectly - through a gear assembly - by a motor. It intermeshes with a female rotor having six cavities. Figure 1 explains the compression mechanism:

(1) Atmospheric air is drawn into the stator by the suction action of the two rapidly rotating rotors.

(2) As the rotors rotate past the intake port, air is trapped in the stator and in the cavities between the rotors.

(3) Further movement of the rotors causes an increased reduction in volume, compressing the entrapped air.

(4) Compressed air is expelled at the discharge port in the bottom of the stator at a pressure and quantity determined by the particular compressor rotor design parameters, such as length, diameter, and speed.

Radial bearings on the male and female rotors compensate for radial loading on the shaft and position the rotors within the stator. Thrust bearings on the discharge end of the compressor prevent rotor misalignment due to thrust developed during the compression cycle.

This design prevents the male and female rotors from making contact with each other or the stator. A clearance of 0.07 to 0.1 mm (0.003 to 0.005 in.) exists between the two rotors and the stator. For

this reason, there is virtually no wear on the rotors or stator, and the unit is relatively maintenance-free.

Oil is injected into the compressor and serves to cool, seal, and lubricate. When air is compressed from atmospheric pressure to some higher discharge pressure, a specific amount of heat is produced. This heat is sometimes referred to as the adiabatic heat of compression. It is partially removed by injecting oil into the compression chamber.

Premachined strips - a raised surface on the male rotor and a

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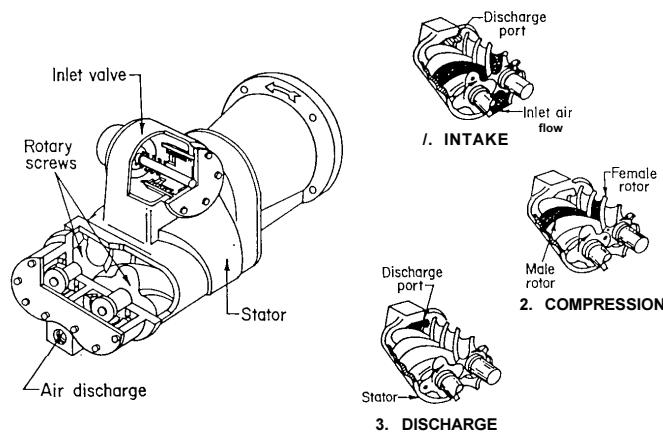


Fig. 1 - Rotary screw compressor.

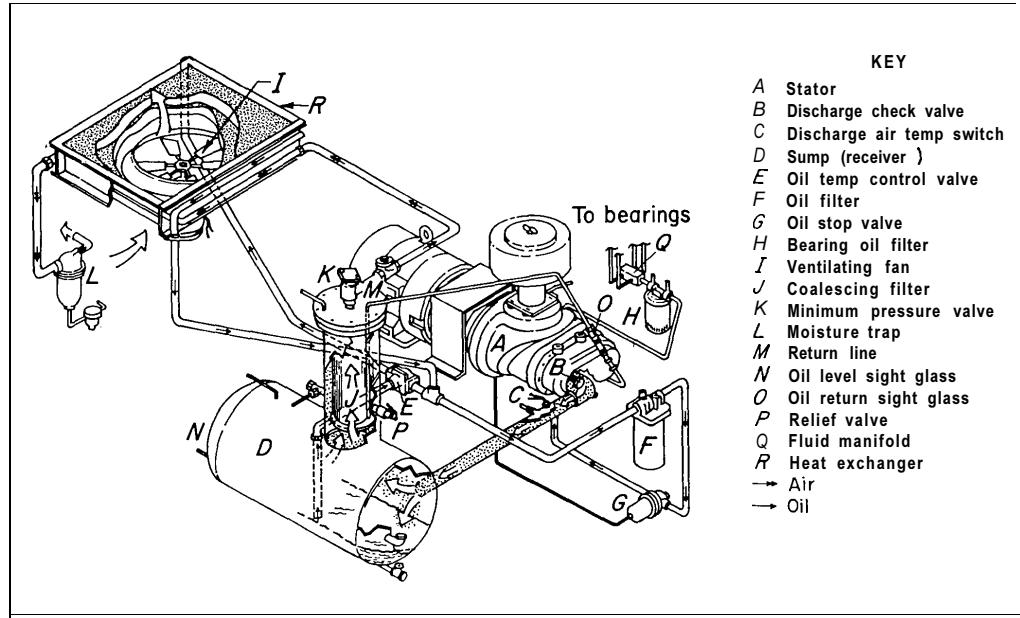


Fig. 2 - Air and oil flow - rotary screw compressor.

groove on the female - provide sealing in conjunction with the lubricating oil and restrict any air slippage back to the inlet side of the stator.

The actual operation of the OFRSC can be broken down into three sections: air production, air control, and the electrical system. A detailed description of the electrical and air control systems is beyond the scope of this article. General knowledge of the air production mechanism is essential, however, to understand events that can lead to a fire or explosion.

Figure 2

Discharge air and oil mist exit the stator (A) through the discharge check valve (B). Discharge air temperature switch (C) monitors temperature of existing air. The air/oil mist enters the sump (receiver; D) where a change in velocity and direction results in the separation of most of the oil from the compressed air.

Hot oil from the sump is directed to a temperature control valve (E). Below temperatures of about 60°C (140°F) the oil is directed back to the compressor through the oil filter (F) and oil stop valve (G) for cooling, sealing, and lubricating.

Oil used to lubricate the bearings undergoes further filtering in

the bearing filter (H) and passes through the fluid manifold (Q) where it is directed to the thrust and radial bearings.

At about 60°C (140°F), a thermal element in the temperature control valve (E) causes it to open. This allows a portion of the oil to be transported through a radiator-type tube/fin assembly (R) where it is cooled by directing air over the tubes by a ventilating fan (I). It then returns to the stator where the cycle is repeated. As a safety feature, the ventilating fan (I) must be operating before the compressor motor can be started. At about 76°C (170°F), the control valve is opened completely, directing all of the oil to the cooler.

The oil that does not separate out in the sump is carried with the high pressure air to the coalescing filter (J). This filter contains pads of fiberglass that remove the remaining oil. Small quantities of oil, collecting on the dry side of the coalescing filter, are drawn back into the stator through the return line.

Virtually oil-free air exits the coalescing filter on the dry side and arrives at the minimum pressure valve (K). This valve is designed to remain closed until the pressure in the sump reaches about 276 kPa (40 psig). This ensures that a driving force will exist to move the oil through the system. The driving force is the

pressure differential between the sump and the intake air orifices to the compressor. At pressures above 276 kPa (40 psig), the valve will open, allowing compressed air to be transported to the delivery line.

In many compressors, the air makes a final pass through an aftercooler, usually in the form of a radiator-type assembly (R). This removes additional heat of compression before delivery. Upon exiting the aftercooler, the air passes through a moisture trap (L) that collects any residual moisture produced.

The main purpose of the discharge air check valve (B) and the oil stop valve (G) is to prevent oil at high sump pressure from flooding the compressor when the machine is shut down. This discharge air check valve is spring-actuated and requires pressure from within the stator to open. The oil stop valve receives a pneumatic signal on start-up from the discharge air end of the compressor. This allows a piston to open the valve, permitting oil flow into the compressor.

The temperature control valve (E) is installed in the unit because it is important to provide a minimum discharge air temperature of about 60°C (140°F). If the compressor is continuously operated below this temperature, moisture can form within the stator and

lead to corrosion, early bearing failure, and excess water in the discharge lines.

Visual indications of oil quantity in the sump and return oil flow from the coalescing filter are provided by sight glasses (N) and (O), respectively. A pressure relief valve (P) opens if abnormally high pressure develops in the unit. Some OFRSC's have an over-pressure switch that shuts down the unit if this occurs.

### Fire and explosion hazards

For a fire to develop, oxygen, fuel, and heat or an ignition source must be present, all at the same time. Removal of any one of these elements will extinguish the fire.

In a compressed air system, sufficient oxygen is present in the air being compressed. The fuel is the lubricating oil in the system. Virtually all lubricating oil used in mining is of the mineral-based type. A typical industrial OFRSC will require between 75 to 115 L (20 to 30 gal) of oil for proper operation. The ignition source may be friction or the heat of compression. This differs from one situation to another, depending on the particular type of compressor involved.

### Flash point

The flash point of the lubricating oil used in a compressor is often mentioned by those investigating a fire or explosion. Most mineral-based oils display flash points in the vicinity of 149° to 204°C (300° to 400°F) at atmospheric pressure.

The flash point of a liquid is defined as the temperature at which a liquid gives off vapors sufficient to form an ignitable mixture with air near the surface of the liquid within the test vessel. An external energy source must be present to cause the liquid to ignite at or above its flash point.

In typical OFRSC's, there is no mechanical contact between the screws and stator and the screws themselves. Thus, there is no significant friction generated between properly maintained moving screws. Barring any bearing failure or misalignment, an ignition source is generally not present. This added with the fact that the flash point of a liquid will increase with increasing pressure. All of this makes flash point ignition by friction an unlikely fire initiation mechanism.

### Autoignition temperature

The autoignition temperature (AIT) is the minimum temperature required to cause self-sustained combustion in the liquid in the absence of a spark or flame. The important point here is that the liquid will burn at or above its AIT and no additional energy is necessary to initiate this action.

Mineral-based lubricating oils display AIT's of about 315° to 371°C (600° to 700°F) at atmospheric pressure. A reduction in their AIT's is observed at elevated pressures (Perlee and Zabetakis, 1963).

Figure 3 shows the general effect of pressure on the AIT of a

**The discharge air temperature switch shuts down the machine if a cooling problem exists in the compressor. These switches trip when the air temperature reaches 110° to 115°C (230° to 240°F). If the switch is inoperative, the compressor will continue to run and a fire may result.**

mineral-based fluid. At a pressure of 690 kPa (100 psig), the AIT of typical mineral-based fluids decreases to about 232°C (450°F). The presence of rust will lower the values of the AIT at elevated pressures even further (McCoy, 1975).

Oil in an OFRSC cools, seals, and lubricates. As a gas is compressed from initial pressure  $P_1$  to final pressure  $P_2$ , the temperature of the air is correspondingly increased. The thermodynamics of air compression can be used to calculate the final theoretical adiabatic air temperature discharging from a compressor if the initial temperature and compression are known.

Air, initially at 15°C and 101 kPa (60°F and 14.7 psig) and compressed to a discharge pressure of 690 kPa (100 psig), will achieve an adiabatic discharge temperature of 243°C (470°F) in the absence of cooling. Since the AIT's of mineral-based compressor lubricants at elevated pressures of

about 690 kPa (100 psig) are on the order of 232°C (450°F), the importance of maintaining oil flow through the compressor housing for cooling cannot be overemphasized.

All that is necessary for a fire to occur in this type of compressor is a reduction in either oil flow or cooling efficiency, sufficient to cause the discharge air temperature to rise above the AIT of the oil. The three elements of the fire triangle are then present and a fire will result.

Fires have, in fact, been reported in OFRSC's where excessive discharge air temperatures were being developed and have been initiated in laboratory studies where oil flow was purposely stopped or delayed (Zaleiskii, 1981; Laing and Russell, 1980).

There are many causes of high discharge air temperature in OFRSC's. Any one can lead to a fire. Some of those causes include:

- loss of lubricant,
- clogging of lubricant orifices to the screws,
- failure of the oil stop valve, clogging of coolant lines,
- fouling of radiator cooling fins (air cooled compressors),
- clogging of oil filter,
- dirty oil,
- low lubricant levels,
- lubricant oxidized or varnished,
- malfunctioning oil temperature control valve,
- failure of cooling fan, and
- lack of proper ventilation to compressor.

The discharge air temperature switch is designed to shut down the machine if a cooling problem exists in the compressor. These switches are set to trip when the air temperature reaches 110° to 115°C (230° to 240°F). If the switch is inoperative or defective, the compressor will continue to run and a fire may ensue. The fire may be vented to the surroundings through piping between the stator and sump, or orifices in the sump, such as safety valves and air couplings.

Other mechanisms are believed to have caused fires in OFRSC's. They are considered to be low probability events, but they have occurred in industry. Three situations that can cause a fire or explosion in the sump (separator) area are listed.

- Small holes or partial clogging in the coalescing filter can result in the passage of high velocity air. This causes the filter to heat, providing an ignition source

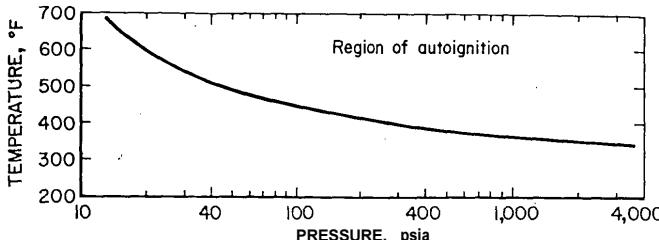


Fig. 3 - Autoignition temperature of mineral-based fluids as a function of pressure.

for the air/oil mist that passes through. Clogging of the filter has been the reported cause of at least one compressor fire investigated by MSHA (1979).

In older compressors where the coalescing filter was ungrounded, static discharge between the sump and the filter was mentioned as a possible ignition source for fires. Newer models incorporate a coalescing filter with staples in the gasket. These effectively ground the filter to the separator tank. Addition of these staples has reportedly eliminated this type of flash fire mechanism.

The coalescing filter can become saturated with oil if the compressor runs unloaded over a period of time. Since the amount of cooling air passing through the filter is reduced, self-heating of the oil in the filter can occur and lead to a fire (Fowle, 1973).

### Minimizing fire and explosion risk

Monitoring the quality of oil in an OFRSC is essential to any maintenance program. Information regarding oil change time periods is included with the particular oil furnished with the compressor.

Most oil packages include a sampling program. This enables samples to be sent to a laboratory for analysis. Based on the test results, the user is furnished with information regarding the current condition of the oil. Most mineral-based lubricating oils require changing after about 1000 hours of operation. Failure to change dirty or varnished oil can result in reduced bearing life and excessive discharge air temperature.

A log of all maintenance operations should be kept. Most compressors are equipped with hourmeters to indicate operating time. Maintenance schedules for checking or replacing lubricants can be correlated with the elapsed time on the hourmeter.

Silicone-based lubricants are available for OFRSC's. Their use in the mining industry, however, has been minimal, mostly due to cost constraints. Although the AIT's of silicone-based oils are higher than their mineral-based counterparts ( $426^{\circ}$  to  $482^{\circ}\text{C}$  or  $800^{\circ}$  to  $900^{\circ}\text{F}$ ), there still have been some reports of fires occurring in OFRSC's using these types of lubricants.

A final problem area associated with the use of OFRSC's, particularly in underground mines, is ventilation. Temperatures in the enclosures housing OFRSC's should be periodically monitored. High temperatures may necessitate additional ventilation to the compressor to avoid overheating and high discharge air temperatures. The manufacturer can be consulted to provide specific information regarding adequate ventilation for a particular unit.

### Summary and checklist

Operation of an OFRSC without proper cooling can lead to autoignition of the oil and rapidly developing fires. A well-planned program of regular safety inspections, maintenance, and personnel training is important if risk of fire or explosion is to be minimized.

Several items that can be routinely checked will warn operators of a potential fire or explosion. The manufacturer's maintenance program manuals contain preventive maintenance timetables and procedures for checking and servicing related components. These manuals should be consulted during regularly planned maintenance or inspections.

The discharge air temperature switch and high pressure switches should be checked to determine if they are functioning properly. The maintenance manuals provide a quick check to determine their operability. These switches must never be defeated

from the electrical wiring systems on the compressor.

The sump and oil return line sight glass levels should be examined to ensure that sufficient oil is present and that the coalescing filter return lines are not clogged. If the sight glass is obscured by dirty or varnished oil, it should be cleaned or replaced. The oil level sight glass and fill cap are located on the sump tank. The fluid level should be about halfway up the glass.

Where applicable, the oil and coalescing filter indicators should be examined. A visual indication on a gauge or a pop-up valve can be seen when these items require maintenance or replacement. Normally, the oil filter will require changing when the pressure differential, across the element, exceeds 103 to 138 kPa (15 to 20 psig). Most oil filter assemblies have a valve that bypasses the filter to prevent oil starvation if a high pressure drop exists. This would deliver dirty oil to the stator, which can cause increased air temperatures and mechanical damage to internal parts. The coalescing filter normally requires changing when a pressure drop of more than 34 to 103 kPa (5 to 15 psig) has developed across the element.

A close inspection around the compressor should be performed to determine any oil leaks that might be present. Loss of lubricant can lead to oil starvation and fire. Examination of discharge air temperature and sump pressure will provide an indication of a potential problem within an operating unit. Normal discharge air temperatures are about  $60^{\circ}$  to  $82^{\circ}\text{C}$  ( $140^{\circ}$  to  $180^{\circ}\text{F}$ ). Higher discharge temperatures may suggest a potential problem.

Air aftercoolers should be checked to ensure the heat exchanger (radiator) is clean and can pass air from the ventilation fan for oil cooling purposes. ■

### References

- Fowle, T.I., 1973. "Air compressor fires and explosions," *Chart Mechanical Engineering*, Vol. 20, No. 6, pp. 64-69.
- Laing, P.D., and Russell, A.G., 1980. "Fires in oil injected screw compressors-Their prediction, analysis, and prevention," *Howden Compressor's Ltd.*, *Mechanical Engineering Publishers Ltd.*, paper C146/80, pp. 19-25.
- McCoy, C.S., 1975. "Fire resistant lubes reduce danger of refinery explosions," *Oil and Gas Journal*, November.
- MSHA, 1979. MNMS&S Cypress Mill, Lyon County NV, accident report, February.
- Perlee, H.E., and Zabetakis, M.G., 1963. "Compressor and related explosions," US Bureau of Mines, IC 8187.
- Zalewski, L.S., 1981. "Increasing operational safety of mine movable compressor stations," *UGOL UKR (Ukrainian SSR)*, Vol. 6, June, 39 pp.