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Guidelines for the Pumping of Water-Based Explosives

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1. INTRODUCTION

1.1 Purpose

This document is designed to be used as a guide on how to meet the requirements of the *Explosives Regulations, 2013* (the Regulations/ER) for the selection, operation, and maintenance of pumps used for water-based explosives. These guidelines may also be used by the Explosives Regulatory Division (ERD) to assist in evaluating licence applications and conducting compliance verifications of sites pumping water-based explosives.

A holder of a licence must comply with all applicable requirements in the Regulations. These guidelines do not serve to substitute the Regulations, and in the event of any disagreement between these two documents, the Regulations shall prevail.

These guidelines do not supersede any other regulation or law, be it federal, provincial, or municipal, or any codes specified in such legislation.

1.2 Scope

These guidelines cover the licensing requirements, pump selection, pumping hazards, safety devices, operation, and maintenance of pumps used for water-based explosives that are classified as Type E.1 blasting explosives under the Regulations (UN0332 or UN3375 explosives), which includes emulsion explosives, slurries and watergels.

Pumping of UN 1.1 explosives in fixed factory installations would be addressed on a case-by-case basis where information in these guidelines is not applicable.

1.3 Definitions

Deadheading is the operation of a pump with no explosive flow due to a closed or obstructed discharge.

Dry running is the operating a pump with no explosives running through the pump.

Hazard Operability Review (HAZOP) is a structured and systematic examination of a process to identify hazards.

Manufacturing includes the following activities:

a) Making or manufacturing an explosive substance from raw material or from another explosive substance;

b) Making or manufacturing an explosive article, including the assembly of an article from explosive and non-explosive components;

c) Altering or remaking an explosive substance or explosive article by modifying its chemical composition (for example, by gassing or blending) or by subjecting it to physical processes with the input of energy (for example, pneumatic handling, pumping, shearing or thickening);

d) Dividing an explosive into its components or unmaking, breaking up or in any manner destroying it;

e) Packaging explosives; and

f) Testing an unauthorized explosive or testing an explosive to assess its potential for a use other than its authorized use.

Mobile Process Unit (MPU) is a vehicle or portable machine that is used at a factory, satellite site or client site to carry out an explosives manufacturing operation.

No-flow is a pump condition where there is no explosives flow within the pump while the pump is operating. This is typically because of deadheading or dry running.

Process unit is a building, structure, room or place in which an explosives manufacturing operation is carried out at a factory.

Quantified Risk Assessment (QRA) is a tool/method that can be used to quantify the risk associated with a specific pumping operation.

Water-based explosives are classified as Type E.1 under the Regulations and include explosive such as emulsions, slurries, water gels (typically classified as UN0332), and Ammonium Nitrate Emulsions (ANEs, classified as UN3375)).

2. REGULATORY REQUIREMENTS

2.1 Activities that do not Require a Licence

The following pumping activities do not require a licence under Part 5 of the Regulations (ER, s. 136) if being conducted at an underground mine or underground construction project:

a) Pumping, thickening, or gassing water-based explosives while charging boreholes; and

b) Blending water-based explosives with ammonium nitrate or ammonium nitrate/fuel oil (ANFO) mixtures while charging boreholes.

Note – if these activities are performed anywhere above ground, then a licence is required under Part 5, Division 1 of the Regulations.

While these activities do not require a licence, the following requirements must be met to pump the explosives (ER, s. 136):

a) The explosives must be on the list of authorised explosives;

b) The equipment used to pump, thicken, gas or blend water-based explosives must be designed to minimize the likelihood of an ignition, including an ignition resulting from pumping against a blocked outlet or from running the pump without any feed;

c) All progressive cavity pumps must be equipped with at least two independent safety shutdown systems to prevent an excessive rise in temperature;

d) If the person is assisted by another person, the other person must be trained to operate the equipment;

e) A preventive maintenance procedure must be put in place for the equipment, including the pumps;

f) Maintenance must be performed by workers who are knowledgeable about the equipment to be maintained; and

g) Precautions that minimize the likelihood of an ignition must be taken.

2.2 Activities Requiring a Licence

All other explosives pumping operations require a licence under Part 5 of the Regulations.

For more information on applying for an explosives licence please refer to *G05-13 - Application Guidelines for Division 1 Factory Licences*.

All applications for an explosives factory licence where pumping activities are performed, including any associated satellite site certificate(s) and client site(s), should include a quantified risk assessment (QRA) or pump hazard operability review (HAZOP) (ER, s. 60(6)(c)), and a description of the pump and its safety features (ER, s. 60(3)(d)).

2.3 Comparison of Regulatory Requirements

The regulatory references throughout this document refer to fixed installations at licensed factories; however, the principles can also be applied to mobile process units and unlicensed pumping underground. Table 2.1 outlines the equivalent regulatory requirements for both mobile process units and unlicensed pumping activities underground.

Requirements	Licensed Pumping		Unlicensed Pumping Underground
	Fixed Installations	Mobile Process Units	
Pump Selection	All pumps must be designed, constructed and installed to conform to good engineering practices (ER, s. 64(1)).	All pumps must be designed, constructed and installed to conform to good engineering practices (ER, s. 93(3)).	All pumps must be designed, constructed and installed to conform to good engineering practices (ER, s. 136(2)(b)).
Pump Hazards and Safety Devices	All pumps must have safety devices selected based on the results of a QRA or HAZOP (ER, s. 60(6)(c)).	All pumps must have safety devices selected based on the results of a QRA or HAZOP (ER, s. 60(6)(c)).	All progressive cavity pumps must be equipped with at least two independent safety devices (ER, s. 136(2)(c)). For other pumps, a QRA or HAZOP should be performed to determine if safety devices are required (ER, s. 20 & 136(2)(g)).
Operating Procedures	Operating procedures must be in place for all pumps (ER, s. 86).	Operating procedures must be in place for all pumps (ER, s. 96(1)).	Operating procedures must be in place for all pumps (ER, s. 19).
Maintenance	A preventive maintenance program must be in place for all pumps, and maintenance must be performed by workers who are knowledgeable about the pump to be maintained (ER, s. 68).	A preventive maintenance program must be in place for all pumps, and maintenance must be performed by workers who are knowledgeable about the pump to be maintained (ER, s. 98(1)).	A preventive maintenance program must be in place for all pumps, and maintenance must be performed by workers who are knowledgeable about the pump to be maintained. (ER, s. 136(2)(e) & (f)).
Training	Personnel using the pumps must be suitably trained (ER, s. 80).	Personnel using the pumps must be suitably trained (ER, s. 80).	Personnel using the pumps must be suitably trained (ER, s. 136(2)(d)).

Table 2.1 – Comparison of Regulatory Requirements

3. PUMP SELECTION

A procedure should be established for the selection of pumps and associated equipment for new systems, or for the modification of existing systems. This procedure must include a QRA or HAZOP for any manufacturing operation that has not previously been used in Canada to manufacture that explosive (ER, s. 60(6)(c)). Any process involving a change in explosives, equipment design, process materials or procedures would be considered a new manufacturing operation.

3.1 General

The pump, and all associated accessories (i.e. seals, hoses etc.) selected, must be designed, constructed and installed to conform to good engineering practices (ER, s. 64(1)) and must be compatible with the explosives being pumped (ER, s. 64(2)).

3.2 Operating Temperatures

The pump should be designed to safely operate at the temperature extremes encountered at blast sites where pumping of water-based explosives operations is to be performed. The temperatures of the explosives at the time of pumping should not exceed the maximum recommended by the pump manufacturer, nor that which is recommended by the manufacturer of the boosters and detonators in a borehole. The pump should operate within the explosive manufacturer's recommended temperature range for the explosives being pumped.

3.3 Operating Pressures

The pump should be designed to safely operate at the pressures typically encountered during the pumping of water-based explosives at blast sites. The pumping pressure should not exceed the maximum limits specified by the pump manufacturer, nor that which is recommended by the manufacturers of the explosives being pumped.

3.3.1 Minimum Burning Pressure (MBP)

Pump systems should be designed, whenever possible, to prevent the pump pressures from exceeding the minimum burning pressure (MBP) of the product being pumped. If ignition occurs in a water-based explosive at pressures above the MBP, then sustained burning of the explosives can occur, causing pressures to rise rapidly to the point of deflagration that may be followed by a detonation within the pump.

3.4 Explosives Viscosity

The pump selected should take into consideration the apparent viscosity at the lowest foreseen explosives-pumping temperature, to maintain full flow to the pump inlet and reduce the possibility of pump cavitation or air entrainment within the explosives.

4. PUMPING HAZARDS AND SAFETY DEVICES

4.1 Hazards

Hazardous conditions can develop within a pump under a variety of circumstances, including allowing the pumps to operate while deadheaded or running dry. These situations can often lead to excessive heating, and this can increase the chance of a subsequent explosion within the pump. QRAs or HAZOPs must be used to determine the appropriate safety devices for a pumping system, if that system has not been previously used in Canada (ER, s. 60(6)(c)).

4.2 HAZOP

A HAZOP is a structured and systematic examination of a system to identify hazards. The HAZOP should include at least the following considerations:

a) Nature of the explosives being pumped (including explosives MBP);

b) Conditions at the pump inlet and outlet;

c) The pump design and the power source;

d) Pump controls (including speed, pressure, temperature and flow);

e) The environment around the pump;

f) Instrumentation; and

g) Operator and operating procedures.

The HAZOP should consider the following items to prevent excess energy or energy concentration, incompatibilities, and unsafe conditions:

a) Explosives confinement;

b) Running the pump in reverse;

c) Pump torque;

d) Internal or discharge pressure;

e) Friction;

f) High explosives temperature;

g) Impact (particularly metal to metal);

h) Compatibility of construction materials, including metals (e.g., copper and copper alloys such as brass or bronze must not contact ammonium nitrate products), lubricants, and the explosives being pumped;

i) Compatibility of the electrical classifications and the environment of use;

j) The properties of the explosives as they relate to the type of pump being used;

k) Voids or cracks in metal components;

l) Explosives contamination by tramp metal, dirt or grit; and

m) Kinetic energy.

The HAZOP should be based on the expected operating conditions of the explosives to be pumped. The HAZOP should involve the pump designer/manufacturer as necessary and should be performed by qualified persons. Trials should be performed prior to the introduction of any new pump.

Before a new or modified pumping system design is introduced (including changes in explosives, equipment design, process materials, or procedures), the design change must be evaluated as part of a management of change program. The management of change will determine if additional HAZOPs should be performed before implementation of the new or modified design (ER, s. 87(1)).

4.3 QRA

A QRA is a tool/method that can be used to quantify the risk associated with a specific pumping operation. As there are many ways to perform a QRA, the proposed methodology should be approved by ERD prior to use.

4.4 Safety Devices

Pump safety devices should be selected to protect against the pumping hazards determined from a HAZOP or QRA.

Pump safety devices must be installed and maintained in good condition so that they operate as designed while the pump is in use (ER, s. 64(4)).

4.4.1 Primary Safety Devices

Primary safety devices are designed to prevent an upset condition within the pump by automatically shutting down the pump, if the pump:

a) Experiences deadheading;

b) Experiences dry running;

c) Exceeds the design running temperature;

d) Exceeds the design maximum pressure; or

e) Exceeds the maximum specified run time.

The number and types of primary safety devices required can only be determined by a HAZOP or QRA.

Some examples of primary safety devices include:

a) Flow sensor and shutoff switch;

b) Temperature sensor/thermocouple and shutoff switch;

c) High- and low-pressure sensor and shutoff switch; and

d) Timing device and shutoff switch;

Primary safety devices should be failsafe (as much as reasonably possible), such that if the device develops a fault, it will activate the trip and initiate system shutdown.

4.4.2 Secondary Safety Devices

Secondary safety devices are devices that act as back-ups to the primary safety devices. These devices are typically considered quenching devices that are used to release energy from the pump to the outside environment if the primary safety device fails.

Examples of secondary safety devices include:

a) Rupture discs; and

b) Thermofuses.

5. OPERATION AND MAINTENANCE

5.1 Operating Procedures

All pumps must have operating procedures (including procedures to minimize the likelihood of accidental ignition) in place (ER, s. 86(1)). These operating procedures must be kept up to date and reviewed annually (ER, s. 86(2)). Pump operating procedures should include at least the following:

5.1.1 Commissioning

All new pumps and all parts of a new operating system should be checked for the presence of foreign material (e.g. welding slag, gasket material, metal filings, grit, etc.) before being put into operation.

A system leak test should be performed to ensure that all pipe and hose connections are tight and free of leaks.

Pumps should be calibrated before being put into service.

5.1.2 Pre-Operating Checks and Start-Up

Prior to operating an explosives pump, the pump should be checked (and tested if necessary) to ensure that it is in suitable condition to run safely. Pre-operating checks may include:

a) Checking/testing the installed safety devices to ensure they are in working order and adjusted to the proper settings;

b) Checking the condition of all pump suction and discharge lines;

c) Checking that all valves are in the appropriate position;

d) Checking that the pump is lubricated with explosive-compatible lubricant conforming to the pump manufacturer's specifications;

e) Checking the hydraulic fluid levels;

f) Checking that pressure relief systems (if installed) are in place and are of the specified failure rating;

g) Checking that rupture disc vent lines are clear and open (if in use);

h) Checking that the pump is rotating in the right direction; and

i) Checking that the water ring system (if installed) is functional.

5.1.3 Pump Operation

Pumps should not be operated at pressures above either the pump manufacturer's or the explosive manufacturer's maximum pressure recommendations.

The pump should operate within the recommended temperature range for the explosives being pumped and should not exceed the maximum manufacturer's recommended temperature of the boosters and detonators in a borehole.

Switches, alarms and timers should not be disconnected on a pump during operation. Upon activation or an unusual reading of any safety devices or instrumentation, pumping operations should be stopped immediately until the problem that caused the activation has been found and corrected.

If the pump operator notices any abnormal conditions, then pumping operations should be stopped immediately until the problem has been found and corrected.

5.1.4 Shutdown and Restart

Prior to an extended shutdown of a pump, product tanks should be emptied, hoses cleared, and augers emptied of any product buildup.

When restarting a pump after a lengthy shutdown, the pump and explosives manufacturer's recommendations should be followed, in addition to the pump start-up procedures.

5.2 Maintenance

All pumps must have a formal maintenance program established and followed (ER, s. 68(1)). The maintenance program should be based on the pump manufacturer's recommendations and the operating/maintenance history of the pump.

Minor servicing may be done while the unit is in service if the servicing is routine and integral to the use of the pump, and is performed by a competent person (ER, s. 68(2)). All other maintenance or repair work that is done at the factory or satellite site must be done by a competent person who has been issued a work permit (ER, s. 68(3)).

If maintenance or repair work is done outside the factory or satellite site, it must be done by a competent person (ER, s. 68(6)). Any contaminated pumps must be decontaminated before they are taken outside of the site for maintenance, repair or disposal (ER, s. 68(5)).

5.2.1 Pump Calibration

Pumps should be re-calibrated periodically based on the pump manufacturer's recommendations.

Tolerances for pump calibration checks should be established. Pumps which do not meet the calibration checks should be taken out of service until they can meet the calibration checks.

Note – Failure of a pump to pass a calibration check could indicate excessive wear of the pump, an air leak in the suction hose, or a partly blocked suction or discharge hose.

Pumps should be calibrated using the pump manufacturer's recommended calibrating procedure.

Pumps that have been out of service for long periods of time should be re-calibrated before being put back into service.

5.2.2 Instrumentation

Instrumentation must be maintained and calibrated on a routine basis (ER, s. 64(4)). The maintenance program should be based on the manufacturer's recommendations and the operating/maintenance history of the instrument.

5.2.3 Documentation

The work permits issued for maintenance or repair work on a pump must set out the procedures to be followed during the maintenance or repair work and the measures that must be taken before, during and after the work to eliminate any possibility of an ignition (ER, s. 68(4)).

A record of all maintenance and repair work done to every explosive pump must be kept for two years after the date on which the last entry is made. The work permits for the maintenance and repair work must also be kept for two years after the date on which the work is completed (ER, s. 68(7)). The maintenance records should be used to update the preventive maintenance cycles and service requirements.

Each progressive cavity pump must have separate records that sets out the operating history of the pump, and the maintenance and repair work done to it that must be kept at the factory for the life of the pump (ER, s. 68(8)).

6. <u>TRAINING</u>

All operators of pumps should be thoroughly trained in all phases of pump operation, by a competent person (ER, s. 82). When employees have completed the training, they must be certified (ER, s. 83 (1)).

This certification must be either a training record, or a document signed by the person who provided the training (ER, 83(2)). This certification must expire not more than five years after the date of certification.

A training record of work experience must be kept up to date for each employee at the factory or satellite site where they perform their duties. These records must be kept for two years after the date on which the employee's certification expires (ER, s. 83(4)).

If a change occurs in the operating procedures for which the employee was certified, the employee must be trained in the new operating procedures, but the expiry date of the certification must remain the same (ER, s. 83(3).

ANNEX A – WATER-BASED EXPLOSIVES

Water-based explosives can have a wide range of physical and chemical properties.

Ammonium Nitrate Emulsions (ANEs) are ammonium nitrate-based emulsion, suspension or gel classified as UN3375 and meeting the requirements of Special Provision 309 of the *Model Regulations on the Transport of Dangerous Goods*, published by the United Nations.

Blends are mixtures of ANFO or ammonium nitrate with a water-based explosive. Blends may be detonator-sensitive or booster-sensitive. A blend will, in general, have higher heave energy than a straight watergel or emulsion.

Emulsions are typically classified as UN0332 and are explosives in which a super-saturated aqueous solution of oxidizer is dispersed in an oil or oil-wax liquid. The term is not commonly used for an explosive in which an oil fuel is dispersed in an aqueous oxidizer solution. In an emulsion explosive, intimate mixing is achieved between a liquid oxidizer and a liquid fuel. The resulting explosives exhibits a very rapid chemical reaction in the detonation head. Nevertheless, as with slurries, high density results in insensitivity and a lowering of density is necessary to achieve detonator sensitivity or even usually to achieve booster sensitivity. They are commonly blended with ANFO or ammonium nitrate to form a booster-sensitive mix that can be pumped or augered into a borehole. Emulsion explosives and many blends have high water resistance.

Slurries are typically classified as UN0332 and are solids suspended in a thickened aqueous solution of oxidizers. The solids are fuels, self-explosive or not, often with crystals of oxidizer as well. Some dissolved or liquid fuels may be present. The thickener is usually a naturally occurring starch-like flour with long string-like molecules. High-density slurries are normally insensitive to a detonator and may require a minimum booster of as much as 100 grams or more of pentolite, even if they are sensitized with a self-explosive ingredient. At reduced densities, they may have practical sensitivity to a detonator at common temperatures of use.

Watergels are typically classified as UN0332 and are formed by linking the string-like molecules of the thickener in a slurry together by chemical bonds and therefore gelling the solution. This is called cross-linking the thickener. The resulting gel can be surprisingly water-resistant. In general, a well-formed gel cannot be pumped, so slurries are usually cross-linked by the addition of a few tenths of a percent of the appropriate chemicals during pumping. A few seconds to a few minutes later, gelation is achieved. Sometimes a partly cross-linked gel is pumped.

Water-based explosives are generally incompatible with strong acids/bases, copper and some elastomers.

ANNEX B – GENERAL PUMP HAZARDS

Most pump hazards result from some form of energy accumulation, or rapid energy addition within a pump, that can potentially lead to an explosion.

B.1 Energy Accumulation

Pumping water-based explosives is hazardous as it introduces energy (heat and pressure) into the explosives, generally under confinement. Under normal operating conditions the energy accumulation from the pump is minor, and the flow of explosive material through the pump mitigates any excessive build-up of energy. Under abnormal circumstances, the pump can be subjected to no-flow conditions (deadheading or dry running) resulting in excessive energy build-up within the pump. This energy build-up can lead to a rise in temperature, resulting in thermal decomposition of the explosives being pumped. In the worst-case scenarios this can potentially result in an explosion within the pump. Energy can also accumulate within the pump if the explosives being pumped are recirculated in a closed loop. Energy accumulation hazards are typically addressed through safe operating procedures, pump design and the use of safety devices.

B.2 Deadheading

Deadheading is a severe upset condition where the pump operates with a blocked discharge. This is particularly hazardous as the maximum energy is applied to a full pump. Dead heading can often be caused by:

a) Explosives solidifying or becoming too viscous within the discharge side of the pump or the pipes;

b) Running the pump with a valve on the discharge side of the pump closed;

c) Foreign objects entering and blocking the pump discharge;

d) Downstream equipment blockages;

e) Kinked or blocked hoses; and

f) Inadvertent pump operations (electrical or hydraulic faults).

B.3 Dry Running

Dry running is another severe upset condition that occurs when the pump continues to operate without explosives being supplied to the pump suction. Dry running can cause a rapid build-up of heat within the pump and can be caused by:

a) Explosives solidifying or becoming too viscous within the suction side of the pump or the pipes;

b) Running the pump with a valve on the suction side of the pump closed;

c) Foreign objects entering and blocking the pump suction (including build up on screens or poorly blended dry ingredients);

d) Running out of explosives (feed starvation);

e) Inadequate suction conditions for the explosive viscosity and flow rate;

f) Suction pipe too long or too small in diameter; and

g) Inadvertent pump operations (electrical or hydraulic faults).

A partial suction blockage or feed starvation may also lead to cavitation or air entrainment within the pump resulting in damage to the pump.

B.4 Compression Ignition

Compression ignition (or “dieseling”) is a condition where rapid compression of a gas bubble containing fuel and air in the right proportions could ignite and propagate to the explosives. The conditions where this hazard could occur are often found in piston pumps. In running these pumps, a vacuum does exist during the suction stroke that can (if the pump is not flooded) potentially draw a mist of oil into an air pocket from the water-based explosives. This in turn is immediately followed by a pressurization, which could cause adiabatic heating leading to ignition of the mist.

Due to the rapid nature of this hazard, safety devices are often not effective. This hazard should be avoided through pump design and control of operating conditions that could lead to a compression ignition event. Please refer to section C.4.2 in Annex C for more detailed information.

B.5 Mechanical Hazards

Mechanical hazards will be largely dependent on the pump being used. The main mechanical hazards would be related to impact, or a frictional event arising from failure of a pump part or a hard object entering the pump. Limiting the pump tip speed and its associated kinetic energy can reduce the hazards associated with foreign objects entering the pump.

B.6 Chemical Hazards

The main chemical hazards from pumping explosives are related to the compatibility of the explosives being pumped and the materials used in the pumping system. Specifically, ammonium nitrate can react with copper and copper-containing alloys under the right conditions to form the highly impact sensitive explosive compound tetra-aminecopper(II) nitrate (TACN).

ANNEX C – TYPES OF PUMPS AND THEIR ASSOCIATED HAZARDS

The following sections are a collection of information and best practices used by the explosives industry in the past. The information in this annex should not be taken as directions on how to select a pump. It is the stakeholders’ responsibility to conduct the proper analysis to determine what is suitable for their specific operation.

C.1 Diaphragm Pumps

C.1.1 Operating Principle

Diaphragm pumps are often used where high pressures are not necessary and pulsing flow is acceptable.

Double diaphragm pumps alternately pressurize one diaphragm chamber while simultaneously exhausting the opposite chamber, causing the diaphragms, which are connected by a shaft, to move endwise. Air pressure is applied over the entire diaphragm surface forcing the explosives to be discharged. Back-flow preventers (typically ball check valves) are manifolded to ensure that the flow is in one direction only. A four-way air distribution valve directs the application of pressure and allows exhaust. The distribution valve or valves are usually mounted externally. The flow is pulsating and equal from both chambers. Some pumps may contain barrier fluid.

Diaphragm pumps have no rotating parts and, if the outlet becomes blocked, the pump stops and subjects the explosive to a pressure equal to the operating pressure of the compressed air running the pump. Most diaphragm pumps operate with the rate of pressurization developing slowly such that there is generally time to dissipate any heat generated.

C.1.2 Pump Hazard Considerations

Pump Hazards	Considerations
Deadheading/dry running.	Air diaphragm pumps are generally considered inherently safe from deadheading and dry running. Safety devices are typically not required for this hazard.
Compression ignition.	Compression ignition events are not typically a hazard for air diaphragm pumps.
Cavitation and air entrainment.	Cavitation and air entrainment should be avoided through pumping system design. Considerations should include pump speed, suction side configuration, explosives viscosity, and leakage.

Pump Hazards	Considerations
Foreign objects entering the pump.	Foreign material should be prevented from entering the pump suction (such as through the use of a screen).
Threaded fittings and connections.	If threaded fittings or connections are used, heat should not be applied to loosen the joint for disassembly until the pump has been decontaminated. Care should be taken when disassembling threaded connections.
Friction (specifically metal-to-metal contact between the outer piston or piston retainer and the casing).	Excessive friction should be avoided through pump design and a routine maintenance program. Pump clearances should be checked before use and modified if necessary to prevent metal-to-metal contact. The pump air pressure should be limited to the lesser of the pump or explosives manufacturer's recommendation. Packing glands should not be used.
Chemical compatibility.	Pump materials (including air directional valves, diaphragms etc.) that are not compatible with the explosives being pumped should not be used.
Diaphragm failure leading to leakage or, in extreme cases when the exit is blocked, working on explosives that heats up as it is pumped backwards and forwards through a hole in the diaphragm.	Diaphragm pumps should be regularly dismantled to check the condition of the diaphragms and the valve shaft connecting them. This is done to prevent air leakage into the explosive and the possibility of corrosion. If there is a risk of high-pressure air reaching the pump through regulator failure, and the hazard review team considers this a hazard, a pressure relief valve should be installed between the regulator and the pump.
Air valves freezing under certain operating conditions.	Air valves should be routinely inspected and maintained if freezing is a concern.

C.2 Progressive Cavity or Helical Screw Pumps

C.2.1 Operating Principle

Progressive cavity pumps are among the most popular for pumping water-based explosives for both surface and underground applications: two-stage for surface, and three- or four-stage for underground.

They give an almost non-pulsating flow at all pressures and can be designed to handle different maximum pressures.

A progressive cavity pump is made up of a single helical rotor within a double-threaded helical stator. As one cavity diminishes, the opposite cavity forms at the same rate to provide constant, uniform, almost non-pulsating flow and positive displacement. The rotor is typically metal and the stator is typically an elastomer encased in a metal housing and forms cavities 180 degrees apart. The rotor may be connected to the drive by a variety of mechanisms such as a flexible shaft, a double U-joint, or a gear joint.

A pump may have a rotor and corresponding stator long enough to have more than one closed cavity at a time. Each additional closed cavity is called a “stage.”

C.2.2 Pump Hazard Considerations

Pump Hazards	Considerations
Deadheading/dry running.	Progressive cavity pumps should typically be fitted with two independent primary safety devices to prevent deadheading and dry running. Deadheading when the stator is worn can pose a unique hazard such that the pressure increase is insufficient to trigger a shut-down while the temperature increase is not perceived by the usual temperature sensor at the pump outlet. This is likely the most serious condition for these pumps. The pump drive motor should be sized and designed to limit the amount of power it can input to the pump to only what is necessary to operate under normal conditions. It cannot be relied upon to stall when the pump outlet is blocked as a worn stator will continue to rotate and thus there is a need to consider instrumentation. Progressive cavity pumps should also be fitted with a secondary safety device to relieve pressure in the case of burning or reaction of the explosives under pressure.
Compression ignition.	Compression ignition events are not typically a hazard for progressive cavity pumps.
Cavitation and air entrainment.	Cavitation and air entrainment should be avoided through pumping system design. Considerations should include pump speed, suction side configuration, explosives viscosity, and leakage.

Pump Hazards	**Considerations**
Foreign objects entering the pump.	Foreign material should be prevented from entering the pump suction (such as through the use of a screen). The manufacturer's maximum pump operating speed limit, i.e., tip speed, should be considered after possible hazards from the kinetic energy of the moving parts have been examined. Additionally, the chosen pump speed should be dependent upon the characteristics of the explosive being pumped and the pump size.
Threaded fittings and connections.	If threaded fittings or connections are used, heat should not be applied to loosen the joint for disassembly until the pump has been decontaminated. Care should be taken when disassembling threaded connections.
Friction.	Excessive friction should be avoided through pump design and a routine maintenance program. Packing glands should not be used.
Chemical compatibility.	Pump materials (including the stator, rotor, etc.) that are not compatible with the explosives being pumped should not be used.
Entry of the explosive into a hollow rotor or drive shaft.	Hollow rotors and drive shafts should not be used.
Bearing failure due to grit contamination, lack of grease and high rotational speed.	Bearings should be externally mounted and sealed. Bearings should be routinely inspected and maintained.
Premature failure of the rotor-drive connection (if internal) or the seal on a flexible joint or a flexible shaft due to high rotational speed. Hot, water-based explosives may cause rubber gear coverings to wear and break apart.	Flexible drive shafts should be used to reduce safety and maintenance problems with various internal joint designs. When a shaft snaps, stored energy is released. Some designs have a confined space at the drive end where the explosives can potentially accumulate and be confined. If shafts with internal joints are selected, the joints should be of low surface pressure type and properly sealed.

Pump Hazards	Considerations
Explosives build-up in the suction casing that interferes with the essential free rotation of the joints.	Progressive cavity pumps should be dismantled at regular intervals to check the condition of the stator and the sealing of the flexible joints. Maintenance and inspection frequency should be based on the manufacturer's recommendations and the operating history of the pump.
Internal retaining nuts and related parts working loose.	Any internal nuts on the pump should be locked or wired in place.
Explosives migrating into seals when the pump is run in reverse.	Prevention of explosives migrating into the seals when the pump is run in reverse should be achieved through pump design.

C.3 Gear and Lobe Pumps

C.3.1 Operating Principles

Gear and lobe (sometimes referred to as three-leaf-clover pumps) are both positive displacement pumps that operate with the same principles, the main difference being the shape of the rotating elements within the pump housing.

Gear pumps contain, within the housing, a pair of equally sized, meshed, fixed displacement gears, one or both of which may be driven. The rotors on gear pumps are covered with an elastomer to prevent metal-to-metal contact. The explosives are taken away from the entry port by gear teeth that sweep the explosives away between them and the pump casing. The swept explosives are carried around to the exit port. The explosives cannot return along the short path between the rotating gears to the entry port because the gears mesh closely. The gear pump is a positive displacement pump. Slip depends on explosives viscosity and on tolerances between the gears and the casing, both at the sides of the gears and at their perimeter. The pump flow is pulsating, but because of the speed and the number of gears, the pulsations are not usually significant.

Lobe pumps typically have two to three lobes within the housing. The lobes separate opposite the inlet port, explosives are drawn into the spaces between them. The explosives are carried between the lobes and the casing to the discharge port. Leakage or slip depends on the clearances between the lobes and the casing, as with gear pumps. Some lobe pumps may have sleeves, or side-wear plates, or both. Both rotors of a lobe pump must be driven, and lobe pumps are therefore more robust than gear pumps.

C.3.2 Pump Hazard Considerations

Pump Hazards	Considerations
Deadheading/dry running.	Gear and lobe pumps should typically be fitted with one primary safety device to prevent deadheading and dry running.
Compression ignition.	Compression ignition is not typically a hazard for gear and lobe pumps.
Cavitation and air entrainment.	Cavitation and air entrainment should be avoided through pumping system design. Considerations should include pump speed, suction side configuration, explosives viscosity, and leakage.
Foreign objects entering the pump.	Foreign material should be prevented from entering the pump suction (such as through the use of a screen).
Threaded fittings and connections.	If threaded fittings or connections are used, heat should not be applied to loosen the joint for disassembly until the pump has been decontaminated. Care should be taken when disassembling threaded connections.
Friction (specifically related to a close fit to side plates).	Gears and lobes should be covered with an elastomer compatible with the explosives being pumped. Gear and lobe pumps should not be used with emulsion blends with ammonium nitrate prill or similarly abrasive solids. Side plate friction should be examined prior to commissioning the pump.
Chemical compatibility.	Pump materials that are not compatible with the explosives being pumped should not be used.
Explosives confinement in the area of the bushings at high speed may produce heat in the explosives faster than the pump can dissipate it.	Internal components should be inspected and maintained on a routine basis.
Bearing failure (bearing is close to the explosives if not externally mounted).	Outboard external bearings should be used.
High shear (increasing the sensitivity of some formulations).	If the explosives being pumped are not suitable for a high shear environment, a gear or lobe pump should not be used.

Pump Hazards	Considerations
Bushing not lubricated and/or leakage into bearings.	Outboard bearings should be used to avoid leakage into bearings. Lubrication should be performed based on the manufacturers recommendations and the operating history of the pump.
Delamination of rubber to steel gears or lobes, especially caused by hot explosives.	Use gears and lobes covered with elastomer or of solid elastomer. The rotor should be non-metallic and of a material that is compatible with the explosives being pumped.
Lip seal failure on outboard bearing pumps.	Pumps should be routinely dismantled and checked for mechanical damage and the condition of seals.
Over-tightening of packing glands on the drive shaft.	Packing glands should not be used. If packing glands are used, they should be tightened in accordance with the manufacturer's specifications.
Thermite reaction between ingredient aluminum and rust from a steel housing.	If aluminum-based explosives are to be pumped, a non-rusting housing should be used.

C.4 Piston Pumps

C.4.1 Operating Principles

These pumps are made up of a piston in a cylinder with a back-flow prevention device. A fixed volume of explosives is drawn in under suction conditions and, as the piston travels, this is compressed to discharge pressure and extruded through the discharge nozzle of the pump. The flow is a pulsating flow. With a single-action piston, the volume pumped is less on the return stroke. Flow in one direction is controlled by internal or external check valves or by an externally activated directional valve.

C.4.2 Pump Hazard Considerations

Pump Hazards	Considerations
Deadheading/dry running.	Piston pumps should typically be fitted with one primary safety device to prevent deadheading and dry running. A piston pump can, under abnormal circumstances, deadhead. If the piston seal in a

Pump Hazards	Considerations
	double-acting pump leaks extensively, the explosives is pushed from one chamber to the other causing heat to build up. In addition, if the dead volume is large and the force of the pump drive is high, the pump will not stall. These events could lead to excessive heat build-up.
Compression ignition.	Compression ignition events should be avoided through pump design and control of operating conditions. Operating controls include limiting the amount of volatiles present in the explosives, limiting the pump stroke rate (especially during start-up), limiting gas bubble size, limiting pump operating pressures, increasing the water-content of the explosives and ensuring the pump working pressure is below the explosive's minimum burning pressure. Hydraulic-powered piston pumps may require special consideration during the accelerating pressure and vacuum strokes.
Cavitation and air entrainment.	Cavitation and air entrainment should be avoided through pumping system design. Considerations should include pump speed, suction side configuration, explosives viscosity, and leakage.
Foreign objects entering the pump.	Foreign material should be prevented from entering the pump suction (such as through the use of a screen).
Threaded fittings and connections.	If threaded fittings or connections are used, heat should not be applied to loosen the joint for disassembly until the pump has been decontaminated. Care should be taken when disassembling threaded connections.
Friction.	Excessive friction can occur if the cycle rate is too high. The stroke rate should be limited to prevent both heat generation from friction and the risk of compression ignition. The use of metal-to-metal moving parts should be avoided.

Pump Hazards	Considerations
Chemical compatibility.	Pump materials that are incompatible with the explosives being pumped should not be used.

C.5 Peristaltic Pumps

C.5.1 Operating Principle

This type of pump is made up of a resilient hose inside a metal housing. The hose is squeezed by a rotor element. Pumping results from the travel of the squeezed location of the hose downstream as the rotor revolves, pushing the explosives before it and creating suction behind it as the formerly squeezed portion expands. The explosives are in contact only with the inner wall of the hose. The rotor can be fitted with rollers or sliding shoes to squeeze the hose. A liquid lubricant in the housing minimizes friction. Suction capability and discharge pressure can be altered by adjusting the amount of hose compression.

C.5.2 Pump Hazard Considerations

Pump Hazards	Considerations
Deadheading/dry running.	Peristaltic pumps should typically be fitted with one primary safety device to prevent deadheading and dry running.
Compression ignition.	Compression ignition is not typically a hazard for peristaltic pumps.
Cavitation and air entrainment.	Cavitation and air entrainment should be avoided through pumping system design. Considerations should include pump speed, suction side configuration, explosives viscosity, and leakage.
Foreign objects entering the pump.	Foreign material should be prevented from entering the pump suction (such as through the use of a screen).

Pump Hazards	**Considerations**
Threaded fittings and connections.	If threaded fittings or connections are used, heat should not be applied to loosen the joint for disassembly until the pump has been decontaminated. Care should be taken when disassembling threaded connections.
Friction.	Excessive friction can occur if the cycle rate is too high. The stroke rate should be limited to prevent both heat generation from friction and the risk of compression ignition. The use of metal-to-metal moving parts should be avoided.
Chemical compatibility.	Pump materials that are not compatible with the explosives being pumped should not be used.
Loss of lubricant/incompatible lubricant, and consequent hose failure.	Peristaltic pumps should be regularly checked to ensure correct operating pressure to prevent rupture of the pumping hose. The preventive maintenance program should include attention to the shoes or rollers on the rotor and the lubricant level and condition of the hose itself.