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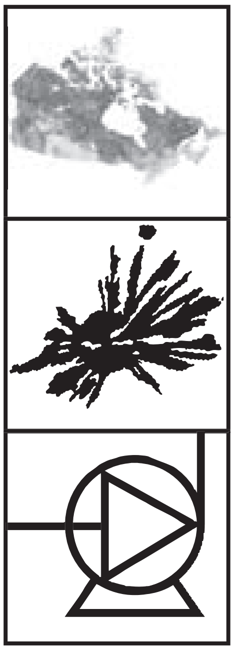

Guidelines for the Pumping of Water-Based Explosives

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Preface

With the introduction of watergels in the mid-1960s and later emulsion explosives, there has been an inherent improvement in safety noted but, despite the increased safety in manufacturing, there still remains a number of pump accidents around the globe, including some fatalities.

From a safety perspective, we at the Canadian Explosives Regulatory Division were concerned about major shifts in recent years in the explosives industry itself due to downsizing and amalgamation. The result has been a number of experienced and highly skilled personnel leaving the explosives industry. At the same time, many of the major manufacturers were downloading new repump technology to less-skilled customers/personnel who lacked the experience and knowledge associated with the traditional explosives industry. All of this, coupled with the incident in Papua, New Guinea, caused us to address the issue of pumping explosives on a more formal basis.

A committee was created that included the major manufacturers and distributors in Canada and the United States, as well as representation from underground mining, the Institute of Makers of Explosives (IME), other provincial regulatory bodies, and equipment manufacturers. Right from the outset, there was real interest expressed by all participants with clear advantages identified in putting industry guidelines into the public domain.

It was not our intent to incorporate these into a new Canadian Regulation but, rather, to form a set of guidelines that would be endorsed by both the explosives industry and the Canadian government in the hope that they will contribute to the safety of explosives pumping.

Much of this document is supported by a good technical footing, but it is recognized that much research remains to be done to characterize the newer explosives and their response to various kinds of energy inputs.

These guidelines bear the names of two authors and some of the authors' opinions appear in them. However, they are primarily a compilation of industry ideas and good industrial practice. If the guidelines prove to be of value, it will be because the industry has been very open in all discussions about safety.

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1. Overview

1.1 SCOPE

These guidelines cover all applications of pumping water-based blasting explosives, be it either emulsion explosives, slurries or watergels, both in the factory and in the field, in open-pit or underground mining and quarrying, and in construction work with the exceptions noted below.

Although it is recognized that detonator-sensitive explosives of UN 1.1 are being pumped in factory (fixed) installations with the appropriate safety precautions, it should be emphasized that this document does not address the pumping of UN 1.1 explosives in the field or in underground operations, i.e., field applications and underground operations are limited to UN 1.5D explosives and blends as classified under the UN Recommendations on the Transport of Dangerous Goods. If consideration is to be given to pumping detonator-sensitive products of UN 1.1 in the field, be it surface or underground, it will be a matter that will need to be resolved individually by industry in conjunction with regulators.

1.2 GENERAL

Pumping of water-based explosives can be extremely hazardous and should be regarded as the critical part of any process demanding the greatest possible attention to pump system design and operational safety. The pumping process is at the heart of factory cartridging and field loading operations, and experience has shown that the degree of hazard depends on the type of pumping system chosen, of which there is a considerable variety. Each pumping application can be reviewed and an appropriate safety system can be designed with the information presented in this document used as a guide to help in the process. To the extent that these guidelines are used, their strengths, weaknesses and errors will be uncovered. They are not intended to stifle innovation in the selection of suitable pumps and their safe operation.

1.3 DEFINITIONS

Authority Having Jurisdiction: The government agency or individual responsible for approving an operation, including its equipment.

Blasting Agent: An explosive meeting the requirements for a UN Classification Code of 1.5D.

Blend: A mixture of a water-based explosive and AN or ANFO.

Cap-Sensitive Explosive: For classification under the UN Recommendations for transportation purposes, an explosive is determined to be sensitive to a detonator by UN test 5(a), when tested between 28 and 30ºC. For the purposes of pumping, the test may need to be conducted at a higher temperature, which will reflect the exposed risk the explosive could be subjected to.

Deadhead (Deadheading): Operating a pump when the discharge is blocked or closed off.

Dry Running: Operating a pump with no material running through the pump.

Emulsion Explosive: An explosive consisting entirely or mostly of a dispersion of microscopic droplets of a supersaturated solution of oxidizing ingredients in a continuous oil or oil-wax medium.

Loading: Pumping explosive in order to fill a blasthole or to supply a cartridging machine.

Matrix: A highly insensitive water-based explosive, usually an emulsion explosive, that may be sensitized to become adequately sensitive through the incorporation of voids, i.e., microspheres, chemical gassing, or the incorporation of air or other bubbles. It is more commonly blended with AN or ANFO to form a practical blasting explosive. (Note: Some jurisdictions classify highly insensitive matrixes as oxidizers but, here in Canada, they are considered explosives.)

Pig (Pigging, Pigged): A plug, commonly polyurethane, moulded to different configurations, densities and sizes so that it can be inserted into and pushed hydraulically (pigged) through a pipe to remove caked material. It is common to clear a line by using air pressure, which is sometimes referred to as "pigging."

Repumpable: The property of a product that permits it to be transferred several times through pumping operations without degradation of the product. Such pumping operations include transfer between, or among, bulk manufacturing sites, bulk storage tanks, bulk transport vehicles, and bulk mix delivery equipment.

Rheology: The relationship in a fluid between shear rate and shear stress. In Newtonian liquids, shear rate is directly proportional to shear stress. No water-based explosive is like that and apparent viscosity at different shear rates cannot be inferred from a single measurement on a viscometer.

Slurry: An explosive consisting of solids mixed with a thickened solution of an oxidizer or oxidizers.

Viscosity: The ratio of shear stress to shear rate in a Newtonian fluid. (**Apparent viscosity** is the ratio of shear stress to shear rate at some particular shear rate in a non-Newtonian liquid.)

Watergel: A slurry explosive in which the thickener molecules have been linked together chemically in order to convert the thickened solution into a gel.

2. Safety Philosophy and Some General Cautions

2.1 Operating procedures and cautions fit within a general safety philosophy. Those aspects of safety philosophy that apply specifically to water-based explosives have been very well described and discussed by the Federation of European Explosives Manufacturers in their "Code of Good Practice on Safety of Machine Design in the Processing of Emulsions and Water-Gels." Their write-up, provided as Appendix III, cautions against complacency about the safety of water-based explosives. It is very well written and **everyone who works with explosives should read it.**

2.2 All pumping operations, and particularly the energy input and flow rate, must be carefully monitored at all times. If for any reason the flow should stop or be interrupted, the operator must immediately shut the operation down, even though he/she may reasonably believe that the mandatory automatic trips will shut the pump down in the next few moments. If the operator should notice any irregularity in the charging pressure input, energy input, or flow of the pumping process, pumping must be stopped at once to determine the reason for that irregularity.

2.3 An explosive and a pump are part of a specified system developed by an explosives manufacturer and the pump supplier, with the explosives manufacturer ultimately responsible for the final specifications.

2.4 Experience with individual systems will determine whether it is necessary to check for hose blockage before charging begins. Often the length of downtime will govern when it is appropriate to flush the system, with a particular emphasis on removing the product in the pump prior to extended shut-down periods. In the case of the emulsification stages of processing emulsions, flushing should be with a suitable medium such as oil, which is often incorporated in fixed facilities. In the case of other stages of processing emulsions or in any stage of processing watergels, flushing should be done with water. In either case, an appropriate hazard review should be conducted to determine whether to capture the flushed residue and separate it for disposal or to be recycled.

2.5 The maximum explosives temperature must not exceed that recommended by the explosive manufacturer nor that recommended by the pump manufacturer.

2.6 Pumping pressure must not exceed the lower of the maxima recommended by the pump manufacturer and the explosives manufacturer. Operating some pumps above their designed maximum pressure, particularly the popular progressive cavity pumps, causes increased slippage and a loss of efficiency with a rise in product temperature or pump failure of a mechanical type.

2.7 The selected pump must be one recommended by the pump manufacturer for products as viscous as the explosive intended to be pumped, bearing in mind that the explosive may sometimes be pumped at temperatures somewhat lower than planned and may have an apparent viscosity of 100 000 centipoises or more.

2.8 The construction materials of every pump must be compatible with the ingredients of the explosives to be pumped, with the explosives manufacturer ultimately responsible for the final selection. One must be particularly careful about possible incompatibilities between rubber stators or other polymeric materials and various oil ingredients. Additionally, oxidizers may form sensitive compounds with copper and brass.

2.9 Safety shut-down systems used on pumps (including such instrumentation as high pressure switches and temperature and flow switches) to detect unsafe conditions and to sound alarms (if desired) should be checked regularly to ensure their reliability.

2.10 Threaded fittings in contact with the explosives in pumping systems should be avoided as much as possible. In spite of good service with threaded fittings on process lines while pumping emulsions and watergel explosives, some have considered them a risk on disassembly, particularly after long disuse and they are dried out. When threaded joints have been exposed to explosives, heat should never be applied to loosen the joint for disassembly until decontamination has been carried out using approved procedures. Threaded fittings must be avoided where molecular explosives such as TNT are used. See additional comments in Section 6.6.

3. Management Responsibilities

Explosives company management should establish procedures for the selection of pumps and associated equipment for new systems or for modifying existing systems. They should include at least:

- A hazard review that includes the pump designer or consultations with the pump manufacturer; and
- Trials before commercial introduction of any pump.

These trials should be closely monitored under specific conditions established by the explosives company.

The management responsible for pumping explosives either in a factory or in the field, whether an explosives manufacturer or user, must:

- Ensure that there are written operating procedures;
- Institute periodic reviews of operating procedures to incorporate improvements or to identify and correct unapproved changes that may have occurred over time;
- Establish a routine preventive maintenance program; and
- Establish a training program for new employees with evaluation and refresher training for experienced employees.

4. The Explosives Themselves

4.1 TYPES

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

Slurries 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 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.

Emulsion explosive is the term usually applied to an emulsion 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 product exhibits a very rapid chemical reaction in the detonation head and consequent high brisance. 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. Many high-density emulsion explosives without any special sensitizer are, for practical purposes, completely insensitive to even a powerful booster. The term “emulsion matrix” is often used to describe them because it is not intended to use them unmodified as explosives. 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.

Blends are mixtures of ANFO or ammonium nitrate with a water-based explosive, either an emulsion or emulsion matrix, as described in the above paragraph, or a watergel. Blends may be detonator-sensitive or booster-sensitive. A blend will, in general, have somewhat lower brisance but higher heave energy than a straight watergel or emulsion.

4.2 EXPLOSIVES PROPERTIES AND CONDITIONS OF USE THAT MAY AFFECT HAZARD

4.2.1 The following is a list, in no set order, of those explosive properties that have been considered to be relevant to the hazard of pumping. It is intended as a checklist only for engineer(s) designing pumping systems to lessen the risk of overlooking one or more explosive properties and conditions that may be important in a particular system.

a) Rheological properties, including possible pseudo plasticity or thixotropy.
b) Minimum ignition energy.
c) Minimum burning pressure.
d) Critical diameter confined.
e) Impact and friction sensitivity under confinement and pressure.
f) Thermal stability under pressure.
g) Minimum practical temperature for pumping.
h) Presence or absence of suspended solids.
i) Nature of suspended solids:
   - brittle
   - friable
   - explosive
   - abrasive
j) Water content.
k) Presence or absence of sensitizers:
   - self-explosive, like TNT
   - not self-explosive, like perchlorates
l) Nature of continuous phase: oil or water.
m) Thermal conductivity.
n) Presence or absence of gas bubbles.
o) Chemical composition of gas bubbles.
p) Gas encapsulated or not.
q) Pressure of gas in encapsulation.
r) Chemical nature of capsules (micro balloons).
s) Presence or absence of flammable volatiles.
t) Degree of homogeneity (droplet or particle size).

4.2.2 Three important conditions of use related to hazards are:

a) Rate of pressurization/pressure differential.
   - Pumping can go from a vacuum to a high pressure in a short time. Conversely, a vacuum can cause bubbles quickly.
b) Cavitation through starvation of feed.
c) Foreign objects - assume they will occur.

5. Pump Construction Materials

a) Pump bodies are commonly made of aluminum, stainless steel, cast iron or carbon steel.

b) Rotors are made of or coated with an elastomer or harder plastic unless the stator is an elastomer, in which case rotors may be made of stainless steel or other metal.

c) Stators of progressive cavity pumps are made of an elastomer that is compatible with the product to be pumped.

d) Lip seals are commonly made of Buna-N, Teflon or Viton. Mechanical seals should be made of ceramic-to-ceramic or ceramic-to-carbon.

e) All hoses should be made of materials that are compatible with the products being pumped. Discharge hoses should have the capability to withstand the temperature and pressure requirements of the pumping system. In addition, suction hoses should be constructed in such a manner to prevent collapse.

f) Hose couplings are made of stainless steel or aluminum or, for low pressure, PVC.

g) Valves are typically made of stainless steel or carbon steel with stainless steel internal parts. Valve seats are typically made of Teflon or Buna-N.

6. Factors Affecting Pump Selection

6.1 OPERATING TEMPERATURES

The temperature operating range must be taken into account in pump selection.

Temperatures of the explosives at the time of pumping must not exceed the maximum recommended by the pump manufacturer nor that recommended by the manufacturer of the boosters and detonators in a borehole.

When pumping hot explosives into a cold pump, differential expansion of the rubber stators and cold steel tubes of progressive cavity pumps may be a problem and demand special operating procedures, particularly for hot watergels. Also, it is important to specify the temperature range when specifying the pump as the thermal expansion of the stator will be six times or more greater than the steel, thus requiring the stator to have a slightly loose fit to allow for expansion.

Heated pump jackets are usually not recommended as they would deliberately be introducing a hot surrounding to the product or residue when a no-flow or deadheaded situation occurs, thereby increasing the hazard.

Most watergels will suffer some crystallization at low temperatures. If low-temperature pumping is foreseen, the pump supplier should be given relevant apparent viscosity information and preliminary testing should be conducted.

6.2 OPERATING PRESSURES

Pump discharge pressures must not exceed the lower of the explosive manufacturer's and the pump manufacturer's maximum recommended pressures. Discharge pressures may be reduced by using a water spray annulus mounted after the pump to lubricate the discharge hose. It will require inspection and calibration.

The pump system selected shall be designed so as to have a flooded pump inlet to maintain full flow to the pump and avoid any possibility of cavitation and entrapment of air in the product. Pump inlets should be leak tested to ensure air cannot be sucked into them. Always try to use the maximum hose diameter and minimum hose length for the pumping application.

An effort should be made to design systems that have pump discharge pressures not more than 180-270 psi (1241-1862 kPa) with these pressures being respectively achieved by standard two-stage and three-stage progressive cavity pumps. Occasionally, when loading upholes, a four-stage progressive cavity pump may need to be used to pump at pressures up to or over 300 psi (2068 kPa) to reduce the amount of inherent slippage generated. In general, two-stage pumps are adequate for surface work. Uniform wall thickness stators can generate about twice the pressure of the usual full elastomer designs with less torque. Having less liner material, they also dissipate heat faster but have the disadvantage that they lead to a quicker loss of pressure with wear.

In general, pressures higher than the minimum (threshold) burning pressures are required for the practical pumping of explosives. Water-based industrial explosives, in general, self-extinguish if they are ignited at atmospheric pressure. The minimum pressure on an explosive to allow self-sustained burning is dependent upon sample size, initial temperature, emulsion droplet size, age of the product, and the presence or absence of a sensitive explosive ingredient (e.g., TNT, but especially water content). There are other factors believed to be of less importance. Provided a large enough sample is used and its age and temperature at the time of testing are those of field use, the minimum burning pressures measured in a laboratory are probably a good guide to behaviour in a pumping system.

Pump systems should be designed, whenever possible, to prevent pump pressures from exceeding the minimum burn pressure of the product being pumped. If ignition occurs in a water-based explosive at pressures above the minimum burning pressure, then pressures can rise rapidly to the point of catastrophic pump failure.

6.3 PRODUCT VISCOSITY

The intended pump supplier should be given apparent viscosity information about the planned explosives to be pumped. The information should include the apparent viscosity at the lowest foreseen product-pumping temperature and a low, as well as a high, shear rate unless the supplier is content with one ball-park figure. Cold weather may raise the viscosity of bulk products to a point where they cannot be pumped without rewarming. A danger in pumping high-viscosity products is the potential to restrict flow into the pump suction cavity and entrap air. As a result, cavitation can occur in situations where adequate flow is not maintained, thereby increasing the sensitivity of the product. **Do not allow pumping to continue if adequate flow is not maintained to the pump inlet.**

6.4 CAPACITY OF PUMPS

Be sure your pump supplier is aware of the full planned range of pumping rates at stated temperatures and delivery pressures and then discuss the possible advantages of a somewhat over-sized pump in order to minimize the speed of moving parts. But oversizing can be overdone, and has been overdone at times, with detriment to pumping efficiency.

6.5 AVOIDANCE OF CHEMICAL HAZARDS

The main chemical hazards are:

- Reaction with copper. Copper or copper alloys must be avoided in all parts of a pump or pumping system. The corrosion products of copper combine with ammonium nitrate to form highly sensitive explosives.

- Degradation of elastomers used in the pump construction or in hoses - see sections 2.3 and 2.8 for responsibility.

- Thermal events that can take place in dead spaces within a pump if there are frictional events to heat explosives in pockets where there is no flow. The most dangerous example is a possible dead space in a hollow rotor. Hollow shafts and packing glands are strongly suspected - see sections 6.9 and 10.3.2 b) and e).

- A specific thermal event, the thermite reaction, that releases much heat and could be the cause of an ignition. The thermite reaction is a reaction of aluminum with iron rust and can be a hazard with aluminized explosives and mild steel or cast iron pump parts.

- A less common thermal event because of reaction between ammonium nitrate and finely divided metals that can be present because of mechanical degradation of pumps.

6.6 AVOIDANCE OF MECHANICAL HAZARDS

The main mechanical hazards are:

- Massive impact or frictional events arising from failure of a pump part or a hard object entering the pump. When a hazard analysis is conducted, the tip speed and the kinetic energy associated with it must be taken into consideration as its limitation may be the only real protection against foreign objects.

- Continuous friction leading to heating of a stagnant pocket of explosive as dealt with under thermal events.

- Discontinuous feed of explosive to the pump, leading to the inclusion of air pockets in the feed with these being subject to compression heating.

- Collapse of a feed hose, leading to starvation of the pump. Suction hoses must be constructed so as not to collapse because full flow to the pump must be maintained at all times. Suction hoses should be kept to a minimum and hard piping should be used whenever possible.

- Tightening or disassembly of threaded joints - see Section 2.10. When it is not possible to design out-threaded joints, liberal amounts of a compatible sealing compound must be used in assembly and safety in disassembly must be addressed, preferably by prior approved decontamination procedures.

- Pump and line blockage problems can occur when pumping products with a high solids content, with perhaps 40% or more solids in an explosives composition, enough to likely cause problems in pumping.

Most mechanical hazards can be avoided by employing somewhat oversized pumps, paying careful attention to clearances of moving parts, avoiding massive friction by the use of suitable elastomers on rotors or stators, and selecting pumps with no dead spaces.

6.7 PUMP WEAR CONSIDERATIONS

Wear can increase the probability of sudden breakage of peristaltic, diaphragm and hollow-rotor progressive cavity pumps. Hollow-rotor progressive pumps must never be used, not only because of the risk of sudden breakage, but also because a weld failure can allow the hollow rotor to fill with explosive that is then susceptible to explosion if the pump runs dry. To avoid pump failure, the operator must send a pump for the replacement of worn parts when a predetermined reduction has been observed in the pump's ability to maintain pressure and output - see Section 10.3.3 j). The use of original or authorized parts is essential.

6.8 POWER REQUIREMENTS

Power requirements are dependent upon pumping rates and back pressure and thus should be estimated carefully so that a limit on speed and power input to the pump can be designed into the electrical or hydraulic power supply to the pump. A compressed air power supply poses a special problem in the control of maximum power and speed input and should not be selected unless the pump is to be under continuous observation and speed control by an operator. If electrical power is used, the appropriate code must be followed. In the case of hydraulics, relief valves or constant pressure systems should be used to provide over-pressure protection.

6.9 SEALS AND BEARINGS

When possible, as with gear pumps and lobe pumps, outboard bearings should be used. Mechanical seals or lip seals are recommended. Packing glands are an inferior choice since there is the potential for frictional heating under confinement. If used, they must have a temperature monitor and high-temperature switch to shut down the pump if a pre-determined temperature is exceeded.

7. Main Risks in Pumping

7.1 Product pumps are at great risk if they are ever:

- allowed to run dry;
- run if product is not flowing (deadheading);
- used to clear blocked lines.

These situations can lead to heating and an explosion.

7.2 Unless safety, under the conditions listed below, has been demonstrated experimentally, most bulk product pumps offer the risk of explosion, especially in factories, if they are ever run without a safety protection system. Most product pump systems must be designed to discontinue pumping automatically, especially in factories, if the pump:

- experiences no flow because of blockage;
- experiences no flow because of product feed starvation;
- exceeds design running temperature;
- exceeds design maximum pressure;
- exceeds unattended running time limit.

Product pumps that pump detonator-insensitive explosives under immediate operator observation in the field may require less instrumentation. Consensus on this point is hard to obtain and is partly dependent on the pump selection.

7.3 The above-noted risks and others are incurred if the following recommended practices are not followed:

- Keep the pumping pressure of hot emulsion at or below the explosives manufacturer's recommendation with a usual maximum of 300 psi (2068 kPa) or 400 psi (2758 kPa) if necessary, for upholes. The concern is pumping beyond the realm of the minimum burn pressure, as well as operating at pressures (and subsequent temperatures) that are above the flash point of most volatiles (see below).

- Monitor the pump temperature internally if possible but, if not, monitor it by the product temperature at the pump exit so as to act on a temperature rise.

- Ensure the absence of dead spots where explosives could lodge and heat or degrade. Remember that a packing gland can be a dead zone and follow the recommendation in Section 6.9.

- Conduct a hazard review before making changes to a pump or product.

- Avoid foreign objects and foreign articles in the explosive.

- Inspect seals and pump shaft connections often.
- Investigate repeated fault-situation shut-downs.
- Use only approved spares for pump maintenance or repair.
- Ensure that air is not sucked into the pump intake.
- Thoroughly train all personnel charged with operating pumping systems for explosives.
- Limit the rate of pressure increase as much as feasible in order to limit the peak temperature of the compressed air pockets with respect to the potential for an event to ignite volatiles in a mix if the volatiles are above their flash point.
- Design and operate the pump at such speeds, i.e., tip speeds, that they are safe even if a foreign object enters them - see sections 6.6 (first paragraph) and 10.3.3 a) for comments on kinetic energy.

8. Pump Start-Up and Shut-Down

8.1 COMMISSIONING

New pumps and all parts of a new operating system should be checked for the presence of foreign material (welding slag, gasket material, metal filings, trash, and grit in the pump, tanks, bins and lines). **Do not use the pump to flush the system.**

The whole system should be checked with water for leaks.

8.2 PRE-OPERATING CHECKS

Check and, if necessary, test the following:

Ensure the pump is lubricated with explosive-compatible lubricant that also satisfies the pump manufacturer's specifications. Water or an oxidizing solution are recommended for watergel operations. New pumps or just-reassembled pumps can be lubricated with mineral oil for emulsion service or ethylene glycol for watergel service. Once used with emulsions, a pump normally contains enough residual oil to provide lubrication. In factory operations, a thin oil-rich emulsion is commonly produced at start-up.

a) Rupture disc is in place and the disc vent pipe is clear and open.
b) Alarms and automatic trips are in working order and adjusted to the proper setting.
c) The water ring spray system is functional.
d) The operator is fully trained.

8.3 START-UP

The operator should review written operating instructions unless the operator has recently operated the equipment or is operating the same equipment repeatedly over a period of time. Nonetheless, the operator should review the operating instructions periodically to ensure that they have not been strayed from.

The operator should ensure by inspection that:

a) Hydraulic controls are in the off position.
b) Hydraulic fluid levels are correct.
c) Pump suction lines are free of leaks.
d) The discharge line and hose are in good condition and free of kinks.
e) The product tank valve open.
f) The vessel vent line is clear.
g) The rupture disc vent pipe is clear and open.

h) The rupture disc is properly rated and properly installed.
i) There is proper fluid level and flow rate in a water ring designed to reduce back pressure by lubricating the discharge hose (if such a ring is present).

If a pump with an elastomer rotor or stator has not been used recently enough to be still wet with an oil or aqueous solution, then pump a small amount of water through it before pumping explosives. Alternately, a lubricant recommended by the pump manufacturer and compatible with the explosives may be used. If the product to be pumped is very viscous, the initial small amount to be admitted to the pump should first be diluted with the explosive's continuous phase to ensure proper lubrication of an elastomer rotor or stator. The walls of tanks or bins should be scraped down to minimize drying out of the product and to ensure that the oldest product is used first. If left to dry, the product could lead to impaired pump suction and cavitation.

CAUTION: Never operate a product pump dry. Damage can occur rapidly. Dry running produces heat that will ruin a pump and can cause fire or explosion.

CAUTION: Never operate a pump against a closed valve or plugged line. The build-up of heat is very likely to cause an explosion. No valve should be downstream of an explosives pump unless it is absolutely necessary. See the final paragraph of Section 11.4, which could apply equally to factory and bulk vehicle operations.

Check that the pump is rotating in the right direction.

Calibrate a new pump and re-calibrate pumps periodically, as often as experience indicates necessary, using the explosives manufacturer's recommended calibrating procedure. Also re-calibrate pumps that have been out of service for a long time. Establish tolerances for pump calibrations outside which a pump will be taken out of service for re-conditioning.

CAUTION: Be sure that a failure to pass a calibration check is truly a failure on the part of the pump. It may be due to an air leak in the suction hose or a partly blocked suction or discharge hose.

8.4 SHUT-DOWN AND RE-START

If a pump is shut down either by a trip or by the operator in response to an alarm, pumping should not resume again until the problem has been identified and corrected.

Before an extended shut-down, product tanks should be emptied and cleaned, hoses should be cleared and "pigged," and augers should be emptied of product build-up. Product removed from a pumping unit before or after shut-down should be inspected and properly disposed of in accordance with its condition. Suction piping to the pump should be disassembled and cleaned.

To re-start pumping after a long shut-down:

a) Inspect the suction chamber of the pump and remove any solid build-up.
b) Inspect the discharge hose for blockage or any signs of damage or deterioration.
c) Remove the rupture disc and carry out an inspection for dead product on the pressure side of the rupture disc (see sections 11.1 and 11.2, 5th paragraph). The rupture disc vent pipe must be clear and open to be effective.
d) Check all pipe and hose connections.
e) Check for caked material in augers.
f) Re-calibrate the pump.
g) Check the operation of all protective devices.

9. Pump Operation

9.1 PRECAUTIONS DURING PUMPING

Never operate a pump at a pressure above the lower of the maximum pressures recommended by the pump manufacturer and the explosives manufacturer.

Switches used to detect high pump pressure and to turn off the driving motor or sound an alarm should be checked regularly to ensure reliable operation.

Never disconnect any switch, alarm or timer on a pump. Upon activation or an unusual reading of any safety instrumentation, stop pumping and do not start again until the problem that caused the activation has been found and corrected.

9.2 BOREHOLE LOADING

Out on a mine or quarry bench, the risk of injury from a truck or hose reel or boom auger is as real as the risk from the explosive.

Great care must be taken in manoeuvring trucks on a blast site.

Hydraulically operated reels and booms must be positioned with the care and safety of personnel in mind. In particular, booms must be returned to a cradle position before moving between blast sites.

Explosives may be pumped into a borehole only after the blasting crew has declared the hole to be checked, prepared and ready for loading.

When a pump has been started to deliver explosive, verify that the product is flowing in the loading hose. Some of the methods are:

- observing hose pulsations;
- observing product flowing into the pump from an open hopper;
- observing product flowing from the end of the hose.

The operator should check that the pump speed and pressure are correct.

Designers and operators should be aware that some pump drives have a potential to overspeed if the load is suddenly removed and overspeed protection has not been designed in.

9.3 CLEARING LOADING HOSES

To clear a hose without the means of compressed air, try:

a) Jogging the pump by manipulation of the controls. In a field operation, there may be a water ring and it may be set to its maximum output before jogging is started.

b) Reversing and jogging the pump momentarily if that can be done and is permitted in the operating procedures following a thorough hazard review of the system. It is particularly important to keep in mind that reversing the pump is considered by many as not a best practice, particularly for progressive cavity (PC) pumps, even if jogging the pump, as it pressurizes the suction housing and puts the pump safety devices in a mode where they cannot operate - see Section 10.3.2 b). If reversing a PC pump:

- There is the potential to push product into dead spaces and to pressurize seals quickly, against their designed use, or to simply blow out the seals;
- Product may be in the seal for a long time in a continuous friction regime;
- There is the potential of pulling downstream sensitized product back into the pump;
- The drive shaft may be subjected to tension, perhaps leading to loosening or premature failure of the couplings or joints.

Reversing a gear or lobe pump is not generally felt to raise the above issues but should be taken into consideration in any hazard review. Centrifugal, diaphragm and most piston pumps cannot be reversed.

At all times when trying to clear a hose by use of the pump, watch for stoppage due to high pressure and be ready to reduce pump speed or stop pumping. If slowdown has been necessary because of partial blockage, then increase pump speed slowly when product flow has been re-established.

If a hose is to be cleared of product by blow-down with air, ensure that the end of the hose is directed into a product tank or a borehole and that the end cannot whip. If the hose is to be blown into a tank, be sure that the end of the hose is clean so as to avoid product contamination and again ensure that the end cannot whip by securing it. Ensure air cannot blow back through the pump. Pumps other than gear or progressive cavity pumps will require a valve to prevent blowback. When air is used to clear the lines, open the blow-down air valve in slow short bursts and wait for results.

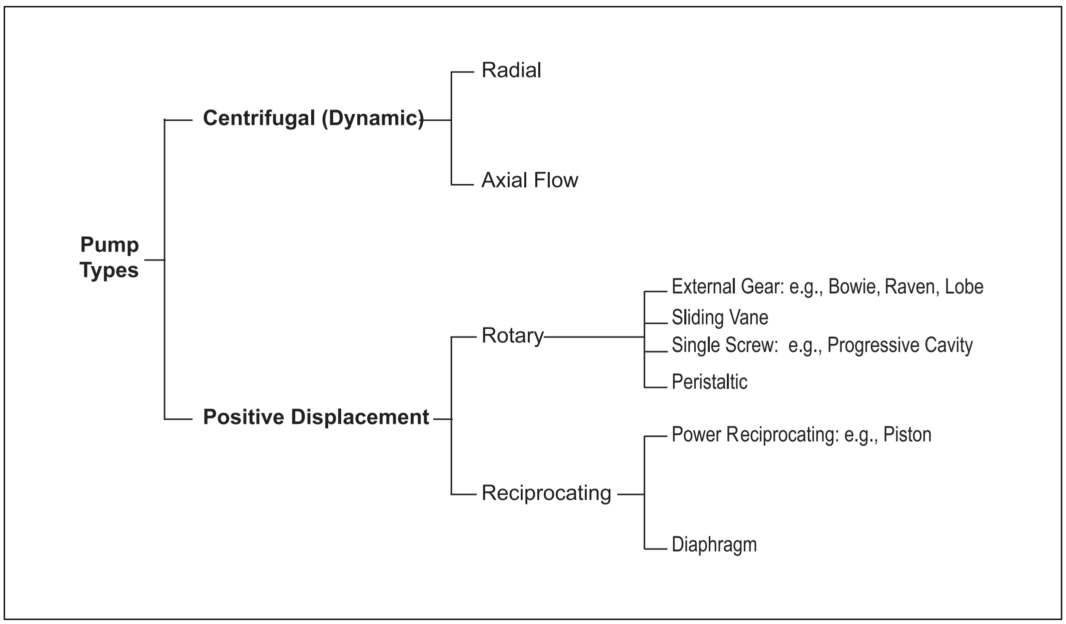
It may be necessary, especially in outdoor operations and more especially in cold weather, to pig a hose after clearing it in order to get efficient further use.

10. Types of Pumps: Operating Principles, Advantages, Disadvantages and Recommendations

PUMP TYPES

Pump types can be grouped under two main categories; *centrifugal (dynamic)* and *positive displacement*. The figure below identifies various pump types found in the explosives industry with most falling under the positive displacement category. There are many other commercial types not included in this listing.

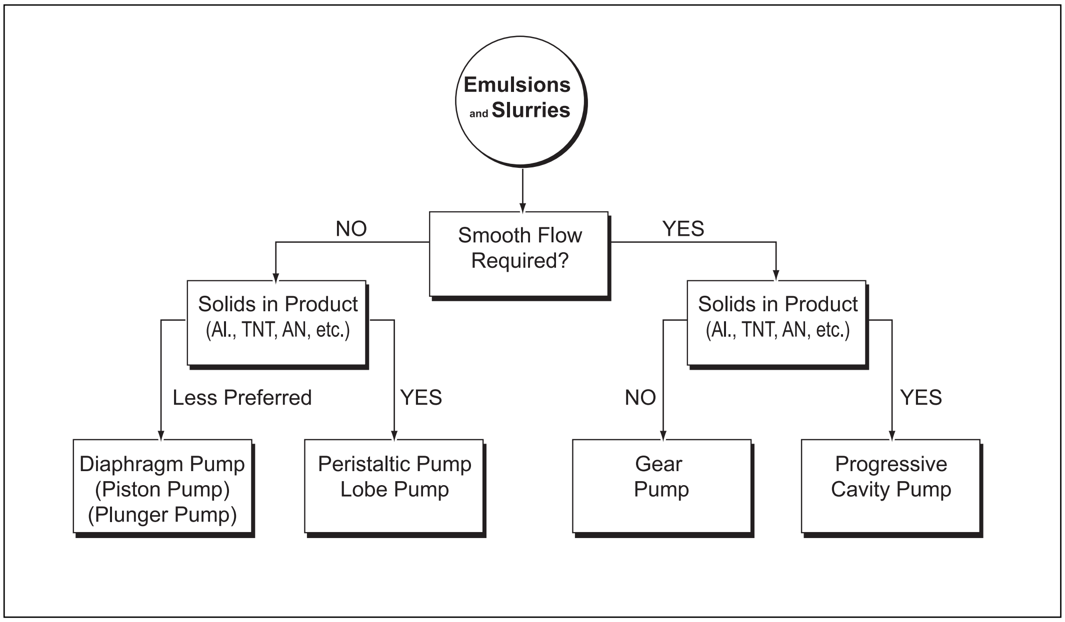
Figure 1
Classification of Pump Types



One major company has developed a decision tree for pump selection. It is reproduced here, with their permission, with one minor modification: peristaltic pumps are grouped with lobe pumps (for solids in the product in a non-smooth flow situation) whereas, in the original, it appeared under the "less preferred" category only along with diaphragm pumps for solids in a non-smooth flow. In referring to the tree, one must realize that it is permissible to use smooth-flow pumps even when smooth flow is not required. An obvious example is the widespread use of progressive cavity pumps.

Keep in mind, with the selection of each type of pump, the intended pump manufacturer's criteria for pressure, speed and viscosity should not be exceeded - see sections 6.1 through 6.4 inclusive.

Figure 2
Decision Tree for Selecting Pumps



10.1 DIAPHRAGM PUMPS

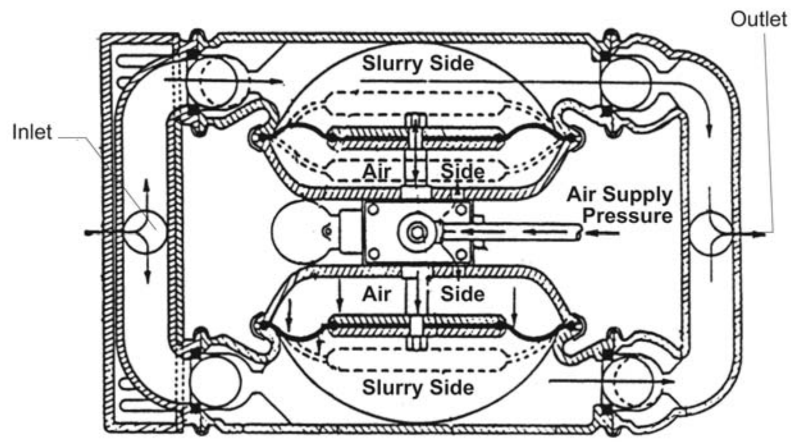
10.1.1 Operating Principle

Diaphragm pumps are the preferred type of pump 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 end-wise. Air pressure is applied over the entire diaphragm surface forcing the product 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. Check valves may be ganged in a single chamber.

Diaphragm pumps have no rotating parts and, if the outlet becomes clogged, the pump just stops and merely subjects the explosive to a pressure equal to the operating pressure of the compressed air running the pump. Most diaphragm pumps used to pump bulk explosives generally operate between 80 and 125 psi (552 and 862 kPa) with the rate of pressurization developing slowly such that there is generally time to dissipate any heat generated. Newer air diaphragm pumps do exist that pump up to 250 psi (1724 kPa) - see Section 10.1.5 i).

Figure 3
Diaphragm Pump



10.1.2 Potential Problems

The problems that have been experienced with commercially available pumps are:

a) Metal-to-metal contact between the outer piston or piston retainer and the casing;

b) Poor “casting” quality with potential for ball guides breaking off;

c) Diaphragm failure leading to leakage or, in extreme cases when the exit is blocked, working on product that heats up as it is pumped backwards and forwards through a hole in the diaphragm;

d) Non-compatible construction materials leading to diaphragm failure or the corrosion of ball valves;

e) Foreign material blocking the ball valve;

f) Air valves freezing under certain operating conditions;

g) This type of pump can greatly overspeed when it empties a tank or hopper and overspeed operations can cause problem a) above;

h) There may be threaded connections that could be a hazard in disassembly - see Section 2.10;

i) Diaphragm failure can result in the product migrating to air directional valves of brass, which may corrode with the formation of sensitive copper ammonium nitrate explosives.

10.1.3 Advantages

Clogging of the outlet normally stops the pump with a small build-up of pressure to full line air pressure, and consequently, there is no danger of adiabatic pressure build-up for the lower-pressure pumps. There are no rotating parts to cause frictional or impact problems. For the same reason, there are no problems with seals.

10.1.4 Disadvantages

Operational disadvantages are that the flow is pulsating and only limited pump pressures can be obtained.

10.1.5 Recommendations

a) Pump clearances should be checked before use and modified if necessary to prevent metal-to-metal contact.

b) On some models it may be necessary to adjust the valve guide length on severely cantilevered guides.

c) Diaphragm pumps must be regularly dismantled to check the condition of the membranes and the valve shaft connecting them. This is done to prevent air leakage into the explosive and the possibility of corrosion.

d) 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.

e) Ensure that all materials are compatible with the products being pumped.

f) Inspection and preventive maintenance should be on a schedule established by the explosives manufacturer.

g) There may be threaded connections that could be a hazard in disassembly (see Section 2.10).

h) Avoid air directional valves made of brass or bronze where feasible; when not, then thoroughly clean them, particularly following a diaphragm failure.

i) The use of air diaphragm pumps up to 250 psi (1724 kPa) may represent no more of an operational or mechanical hazard than those that normally run at 80 to 125 psi (552 to 862 kPa). A decision can only be based on a thorough hazard review.

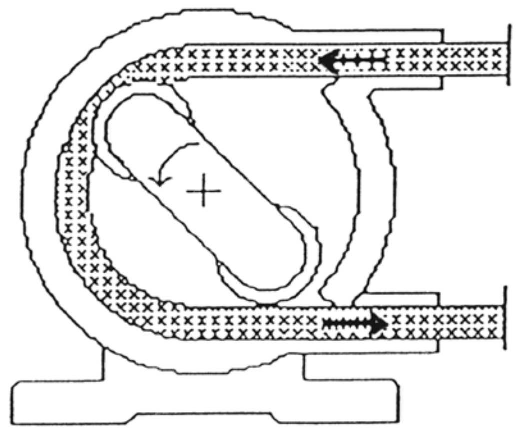
10.2 PERISTALTIC PUMPS

10.2.1 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 product before it and creating suction behind it as the formerly squeezed portion expands. The product is 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.

If explosive blocks the pump outlet, overheating can occur. Running dry will result in a burst pumping hose. To prevent this, the pressure side of the pump must be equipped with a flow meter, control, and rupture disc. The intake hopper should have level switches that automatically shut down the pump if the level becomes too low.

Figure 4
Peristaltic Pump



10.2.2 Potential Problems

Problems that have been experienced with this type of pump are:

a) Loss of lubricant and consequent hose failure;
b) Incompatible lubricant;
c) Tube rupture;
d) Pump running dry;
e) Presence of foreign material, which causes problems in the hose;
f) Deadheading, which causes heat build-up in the pump;
g) Non-compatible construction materials leading to corrosion and failure.

Peristaltic pumps should be regularly checked to ensure correct operating pressure in order 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.

10.2.3 Recommendations

a) Do not run the pump dry and do not “deadhead” the pump but, in case you do, provide adequate protection devices.

b) Establish an inspection and preventive maintenance schedule in accordance with the explosives and pump manufacturers’ recommendations.

10.3 PROGRESSIVE CAVITY OR HELICAL SCREW PUMPS

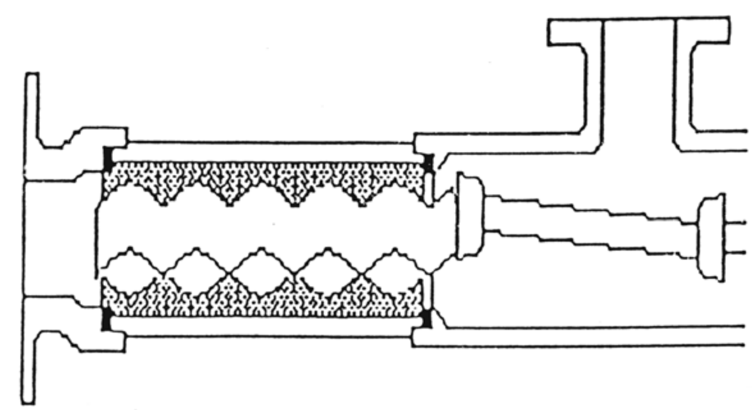
10.3.1 Operating Principle

These 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 metal. The stator is 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." In general, each stage can handle a maximum differential pressure of about 80 to 90 psi (552 to 621 kPa), particularly for abrasive fluids, to ensure satisfactory life.

Figure 5
Progressive Cavity Pump



10.3.2 Potential Problems

The problems that have arisen with these pumps are:

a) Running dry, which leads to overheating (see c) and h) below).

b) Entry of the explosive into a hollow rotor. **Hollow rotors must never be used.** Hollow drive shafts are suspect of having similar problems, especially if the pump is operated in reverse even momentarily when the explosive could by-pass a worn O-ring or other seal and be subjected to heating in a confined space by a hot bearing - see Section 9.3 b).

c) Deadheading leading to overheating. Deadheading may be caused by a closed valve, by blockage by a foreign body, or by a hose containing cross-linked or cold explosive - see a) and h).

d) Cavitation of the product and air entrainment.

e) Friction in the pump or seal. The use of packing glands as seals is not recommended, but see Section 6.9.

f) Bearing failure due to grit contamination, lack of grease and high rotational speed.

g) 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, fresh repumpable emulsion may cause rubber gear coverings to wear and break apart.

h) Overheating from the pump slip, due either to overpressure or pump wear. 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.** See Section 10.3.3 j) for proper maintenance and Section 10.3.3 o) for redundant heat protection.

i) Product build-up in the suction casing that interferes with the essential free rotation of the joints.

j) Internal retaining nuts and related parts working loose.

k) Product migrating into seals when the pump is run in reverse - see comments in Section 9.3 b).

l) Wear and failure of the booted joints on connecting shafts.

10.3.3 Recommendations

Progressive cavity pumps are widely used and, consequently, comprehensive recommendations on their design and proper operation have been clearly established, giving particular emphasis to the precautions to observe. These are:

a) Product viscosity and pump inlet design are major factors in determining the safe operating speed. This speed must be low enough to prevent air entrainment or cavitation, particularly under cold, thick product conditions, and should never exceed the desired design pump rates or manufacturer's maximum rate. 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. The possibility of foreign objects being present should not be overlooked as they cannot be kept out of the system reliably. Additionally, the chosen pump speed should be dependent upon the characteristics of the explosive being pumped and the pump size rather than arrived at by an arbitrary figure.

b) The stator must be nonmetallic and of a material that is compatible with the explosive.

c) The stator and rotor must be designed to handle the desired operating temperature.

d) The rotor must be of solid material so that there is no build-up of material in a hidden area.

e) Flexible drive shafts are recommended to eliminate safety and maintenance problems with various internal joint designs, but it must be recognized that these too have problems and fatigue when the surface gets damaged/scored through the ingress of foreign objects or abrasion. When a shaft snaps, stored energy (difficult to quantify) is released. Some designs have a confined space at the drive end where the product can potentially accumulate and be confined. If shafts with internal joints are selected, the joints must be of low surface pressure type and properly sealed.

f) Bearings should be externally mounted and sealed.

g) Any pump used for detonator-sensitive product must be fitted with a rupture disc to relieve pressure in the case of burning or reaction of the product under pressure, whether the burning is started by pumping against a blockage or otherwise - see sections 10.3.2 h) and 11.3 for further considerations under a worn stator condition.

h) 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.

i) These helical screw pumps must be dismantled at regular intervals to check the condition of the stator and the sealing of the flexible joints. A check every 1000 tonnes of product pumped has been suggested but the frequency will depend on the solid particulates in the product and other factors. Actual inspection frequency will have to be determined through experience with the products, systems and operating conditions.

j) Wear during normal operation reduces the pressure and capacity output. To compensate, the pump speed is usually increased gradually, creating internal slippage and product degradation. Increasing the speed to compensate for a worn stator (to increase capacity) also leads to higher tip speeds, prematurely worn joints and other kinetic energy considerations, particularly when foreign objects fall into the pump, with respect to impact and friction. Similar concerns arise if the pump has been specified to be too small for the task and it is operated beyond the recommended maximum speed set by the explosives manufacturer.

   Product degradation and lost efficiency often signal that a change is warranted for the elastomer element. One explosive manufacturer suggests that when 80% of the calibrated flow rate is reached, it is time to change the stator (see Section 6.7). When the stator is being checked, attention should also be paid to the rotor, although it will generally outlast several stators. A visual inspection will often suffice. If the chrome plating is worn through to the base metal, the rotor must be replaced.

   One prominent pump manufacturer recommends that the wear of a rotor may be checked by comparing the crest-to-crest diameter with the manufacturer's published value. If the diameter is within 0.010 inch (0.254 mm) of the published figure and the rotor is free of deep nicks, gouges or pits, the rotor is re-usable. While performance is the best measure of rotor-to-stator fit, a quick assessment is possible. If the dry rotor can be inserted into a new stator, the rotor should be replaced. If a wet rotor can be inserted with a moderate amount of effort, the rotor is worn but probably still usable.

k) A preventive maintenance program provided by the explosives manufacturer must be followed, particularly for critical components such as bearings, internal connections, seals, and flex shafts.

l) Any internal nuts on the pump should be locked or wired in place.

m) Lip seals are strongly recommended and a few manufacturers will retrofit two, one in reverse, with a compatible grease in between, although it is recognized that the product could weep between two seals that are not lubricated adequately in between. The explosive can act as a lubricant for seals, and manufacturers have also added a wear-resistant material on the shaft to prevent seals from wearing rings on the shaft itself.

n) There may be threaded connections that could be a hazard in disassembly - see Section 2.10.

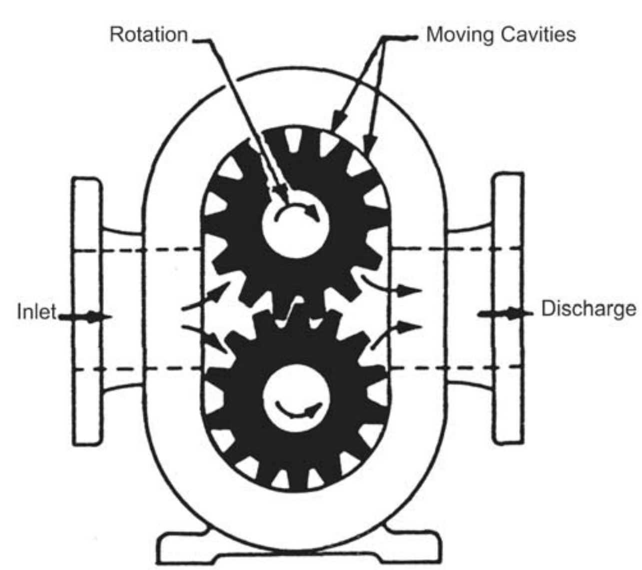
o) The mechanism of product heating for PC pumps is unique and must be guarded against - see Section 10.3.2 h). Redundant protection against heating is essential. The major cause of heating is no flow.

10.4 GEAR PUMPS

10.4.1 Operating Principles

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 product is taken away from the entry port by gear teeth that sweep the product away between them and the pump casing. The swept

Figure 6
Gear Pump



product is carried around to the exit port. The product 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 product 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.

There are some reservations about the safety of using gear pumps to pump explosives. On the other hand, the large facing plates on this kind of pump could usefully act as huge bursting discs, especially if engineered bolts of designed strength were used to fasten the facing plates in place.

Certain elastomers degrade with time, especially when exposed to sunlight or fluorescent light. Proper storage should be maintained.

10.4.2 Potential Problems

The problems likely to be encountered with gear pumps are:

a) High friction (close fit to side plates).

b) Product confinement in the area of the bushings at high speed may produce heat in the explosives faster than the pump can dissipate it.

c) Bearing failure (bearing is close to the product if not externally mounted).

d) Pump running dry.

e) Presence of foreign material.

f) Deadheading may result in heat build-up in the explosive in the pump. Drive selection is important (see Section 11 reference to instrumentation and hazard review).

g) Air entrainment.

h) Non-compatible construction materials.

i) High shear (increasing the sensitivity of some formulations).

j) Bushing not lubricated and/or leakage into bearings.

k) Delamination of rubber to steel gears, especially caused by hot explosives.

l) Lip seal failure on outboard bearing pumps.

m) Overpressure of pump beyond manufacturer’s recommendations.

n) Over-tightening of packing glands on the drive shaft.

o) Thermite reaction between ingredient aluminum and rust from a steel housing.

10.4.3 Recommendations

a) Inspect internal components routinely.

b) Lubricate in accordance with a preventive maintenance program that meets the recommendations of the pump or explosives manufacturer.

c) Calibrate often to monitor wear.

d) Bare metal gears must never be used. Use gears covered with elastomer or of solid elastomer.

e) Product viscosity and pump inlet design are major factors in determining safe operating speed. This speed must be low enough to prevent air entrainment or cavitation under cold, thick product conditions.

f) Outboard external bearings are strongly recommended.

g) Lip seals are strongly recommended.

h) If aluminum product is to be pumped, it is recommended that a non-rusting housing be used.

i) Reservations about gear pumps with explosives are lessened if applications only require large-diameter hoses of short length.

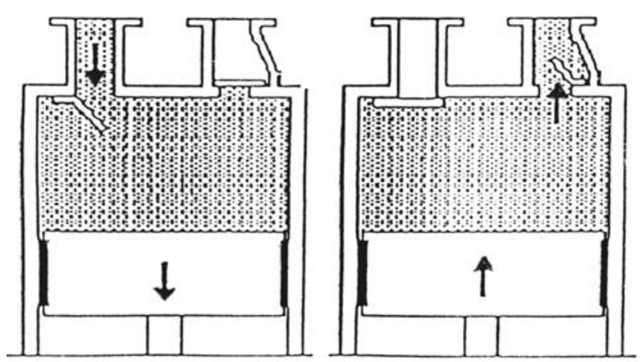
j) There may be threaded connections that could be a hazard in disassembly (see Section 2.10).

10.5 PISTON PUMPS

10.5.1 Operating Principles

These pumps are made up of a piston in a cylinder with a back-flow prevention device. A fixed volume of product is drawn in under suction conditions and, as the piston travels, this is

Figure 7
Piston Pump



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.

10.5.2 Potential Problems

Potential problems are:

a) A piston pump can, under abnormal circumstances, deadhead. If the piston seal in a double-acting pump leaks extensively, the product 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 heat build-up.

b) Excessive friction can occur if the cycle rate is too high.

c) Adiabatic compression of entrapped air either in the chamber or within the explosive, particularly with a high-viscosity product. 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 emulsion. This in turn is immediately followed by a pressurization, which could cause adiabatic heating leading to ignition of the mist.

d) Generation of very high pressure, with the unfortunate effect that if ignition occurs in the pump, the explosive burn rate will be high.

e) Non-compatible construction materials.

10.5.3 Recommendations

a) Do not run the pump dry; provide adequate protective devices.

b) Prevent introduction of tramp metal.

c) Clean thoroughly before storage.

d) There must be no metal-to-metal moving parts.

e) There may be threaded connections that could be a hazard in disassembly (see Section 2.10).

f) Hydraulic-powered piston pumps require special consideration during the accelerating pressure and vacuum strokes.

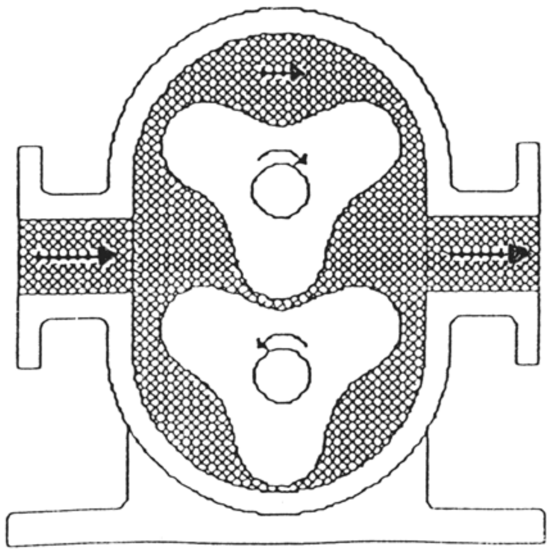
10.6 LOBE PUMPS OR THREE-LEAF-CLOVER PUMPS

10.6.1 Operating Principle

This type of pump can be used in almost any kind of pumping of water-based explosives.

A lobe pump is a rotary pump similar in principle to the gear pump (typically two or three lobes). As the lobes separate opposite the inlet port, product is drawn into the spaces between them. The product is carried between the lobes and the casing to the discharge port. Lobe pumps are positive displacement pumps. 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.

Figure 8
Lobe Pump



10.6.2 Potential Problems

The problems that may arise with these pumps are:

a) High friction; close fit to side plates.

b) Pump running dry.

c) Foreign material causing jams, overheating, and destruction of the pump.

d) Deadheading may result in heat build-up if explosives are in the pump. The selection of the drive is important (see Section 11 reference to instrumentation and hazard review).

e) Cavitation of product and air entrainment.

f) Product confinement in the area of the bearings/bushings.

g) Bearing failure.

h) Non-compatible construction materials.

i) Delamination of rubber covering of steel lobes.

j) Overpressure of pump beyond the manufacturer's recommendations.

10.6.3 Recommendations

Lobe pumps are widely used and there are extensive specific directions issued. In particular, the precautions that must be taken to ensure safe operation are:

a) Product viscosity and pump inlet design are major factors in determining safe pump operating speed. This speed must be low enough to prevent air entrainment or cavitation under cold, thick product conditions.

b) The rotor must be nonmetallic and of a material that is compatible with the explosives being pumped.

c) The pump must be designed to withstand planned operating temperatures.

d) Lobe pumps should be dismantled and checked for mechanical damage and the condition of seals at least after every one thousand tonnes of explosive pumped.

e) Drive mechanisms must be lubricated on a maintenance schedule in accordance with the manufacturer's recommendations.

f) Metal lobes in a metal case must be covered with rubber or other elastomer and the pumps should be calibrated often to monitor wear.

g) There may be threaded connections that could be a hazard in disassembly (see Section 2.10).

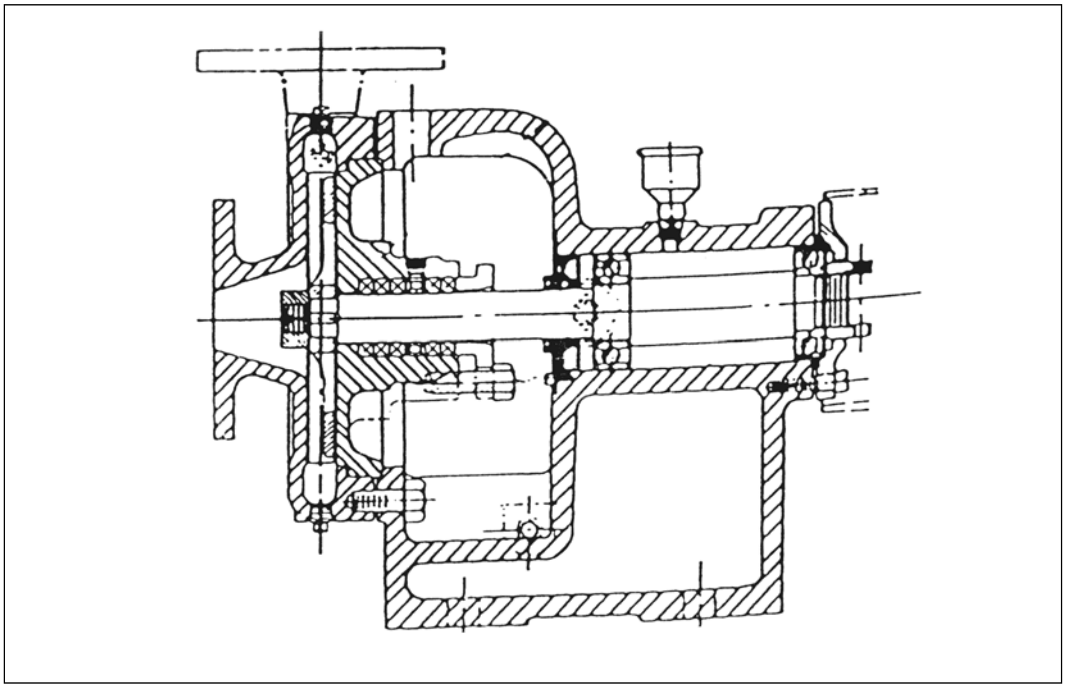
10.7 CENTRIFUGAL PUMPS

10.7.1 Operating Principle

The essential elements of a centrifugal pump are: (1) the rotating element, consisting of the shaft and the impeller; and (2) the stationary element, consisting of the casing and bearings. In the pump the liquid is forced by either atmospheric or other pressure into a set of rotating vanes that constitute an impeller which discharges the liquid at a higher pressure and a higher velocity at its periphery.

Centrifugal pumps are used to pump water-based explosives only for transfer from one vessel to another through short lines of low resistance to flow. Even in that application they are seldom used; however, they are commonly used to pump oxidizer solutions.

Figure 9
Centrifugal Pump



10.7.2 Advantages

A centrifugal pump has the advantages of:

a) Low cost.

b) Non-pulsating flow.

c) Self-limiting maximum pressure, set by the rotational speed of the drive motor.

d) Low internal pressures near the drive shaft, simplifying the design or selection of a seal.

10.7.3 Disadvantages

The disadvantages of a centrifugal pump are:

a) There is no pressure rise to warn of a deadheaded situation. Therefore, one needs a reliable no-flow indicator or a sensitive, fast-response temperature probe in the body of the pump with high-temperature cut-out.

b) When deadheaded, a centrifugal pump will not stall and, although the power demand drops substantially, there is still enough power going into the explosives or oxidizer in the pump to heat it up very fast.

c) Cavitation is likely to occur unless the product has a very low viscosity.

d) One is intuitively afraid of the high tip speed of the rotor.

10.7.4 Potential Problems

a) High friction.

> **CAUTION:** Removal of the shims on some models results in close fitting of the end plates.

b) Non-compatible construction materials.

c) Some models use a "bleed line" to lubricate seals. If so, a separate water flush is recommended to a mechanical seal rather than using the medium being pumped.

d) Over-tightening of the packing gland nut (if so used) on the drive shaft of some models.

10.7.5 Recommendations

Centrifugal pumps are not recommended by most explosives manufacturers and are prohibited by some.

If, in spite of the disadvantages, a centrifugal pump is used, a high-temperature probe connected to a cut-out switch is essential. This absolute requirement is also valid for oxidizer solutions. Ammonium nitrate has been known to detonate in an oxidizer solution transfer pump left running with no flow.

> It is strongly recommended to not use packing glands for either explosives or oxidizers.

11. Instrumentation and Other Protective Devices

Protective devices are an important part of a pumping system and must be carefully thought through. Most pumping systems for boreholes (see sections 11.4 ii) and 11.5) and all systems for cartridging packaged product must include protective devices designed to prevent or provide warning of unsafe pumping conditions that cover at least the risks addressed in Section 7 with particular emphasis on Section 7.2. Diaphragm pump systems and transfer pumps (generally gear pumps) pumping through unrestricted lines may require less instrumentation. A decision can only be based on a hazard analysis, which may include testing by starving the feed (run dry) or deadheading the downstream line and operating the pump at the intended operating speed.

Operators must be trained to understand the protective devices' purpose and ensure that the instrumentation and associated hardware are carefully maintained to whatever extent possible and never overridden. Checking the systems to ensure they function implies that they sometimes do not work. Even the best system of protective devices will only perform its intended function when the right attitude is imparted on the job and the system is run by a trained operator.

However, protective devices are not a substitute for carefully thought-out written instructions that are conscientiously followed.

Appendix V contains a summary of the approach taken by one committee on instrumentation. Without necessarily being complete, it shows how to systematize thinking to link precautions with identified hazards (see also Section 11.6 for a summary on instrumentation).

> When reviewing a pumping system, some may feel that more instrumentation is of value.

11.1 CHOICE AND LOCATION OF DETECTORS/DEVICES

Flow detectors ideally should be located at the exit to the pump and should be able to detect both low and no-flow conditions, but are generally not reliable. They must be regularly calibrated.

Low-pressure switches set up such that the product pressure must reach a specific minimum pressure within a specified time are available and in use. Low flow detection could be inferred from this low-pressure/timer switch configuration with appropriate arrangements that allow start-up and cleaning once the problem has been rectified.

Pressure sensors should be located at the pump discharge with read-out at the sensor or at the operator's station. Their location is not as critical as temperature sensors, as the former will function as long as they are not separated from the pump by a blockage. Pressure switches used with pressure sensors will trip power to the pump at a setting well below a rupture disc rating or alternatively activate a signal at the operator's station. They must be periodically maintained and checked in accordance with a routine maintenance schedule. Malfunctions are easy to recognize by their variable readings or by readings at the maximum setting. In such cases, these must be corrected immediately.

Warning switches or cut-out switches can be checked by momentarily creating a "deadhead" condition at pressures about 25% below the rated pressure of the bursting disc. Some manufacturers feel that 25% is too large a margin with 25 psi (172 kPa) being suggested. The *operating* pressures will be lower than the test pressures quoted.

Rupture discs should be located directly at the pump discharge and ideally in contact with the flowing product and readily accessible, i.e., in line with the interior surface of the pipe, to eliminate any dead space. A machined block has been effectively tried by one explosive manufacturer. A less desireable alternative is to use a suitably designed coupling or clamp with piping (if any) very short and straight to be effective. The common use of tees and elbows to conveniently locate discs is not a good practice as dead spaces are created where product can accumulate.

A hazard review and/or experimentation and experience to avoid nuisance failures need to be taken into consideration in order to provide late protection well within the pump design safety factor and considerations for the rheology of the product being pumped.

The disc manufacturer's rating label must be relied upon for burst pressure information to ensure that the disc rupture pressure is that desired and is, in any event, below the maximum rated working pressure of the pump.

Rupture discs must be installed according to the disc manufacturer's recommendations and changed on a schedule recommended by the explosives manufacturer in order to ensure rupturing at their rated pressures. This is important as there is no inspection procedure to test the proper operating pressure of rupture discs.

Rupture discs give no warning that access to them from the pump and egress from them via a vent pipe are blocked. For this reason, the access port and vent pipe should be inspected daily and certainly when operations are suspended for long periods of shut-down (see Section 11.2). Knowledge of a particular system will determine what time period is appropriate. Caution needs to be exercised whenever handling, removing (to check) and replacing rupture discs as the chance of damaging the disc increases with handling. It cannot be assumed that routine flushing of the pump and associated piping at shut-down has cleared an access to the disc.

Personnel should be protected from the consequences of a disc bursting (deflector plate).

The use of a weak hose of known rupture strength in place of a manufactured rupture disc has been considered by many in industry to be a poor practice. Such a hose relief device would be difficult to use reliably as hose ratings include a much higher safety factor that, if relied upon, *could yield grave consequences*. Also, hoses do wear quickly with emulsions/watergels containing a high solid content, which in turn can affect its rating.

Thermocouples (T/C) should be placed so as to measure the temperature of the explosive in the pump and stop the pump drive if the temperature exceeds a predetermined maximum, but this involves potentially compromising the integrity of the case and also forms a cavity where product can accumulate and isolate the thermocouple, as well as add to the difficulties of maintaining the pumps. In most cases, a more convenient position is to locate the temperature probe directly at the pump discharge or, alternatively, on the outer surface of the pump via the use of thermally conductive adhesive.

In the case of gear or lobe pumps, the discharge is short and the metal housing or thin side (end) plates give rapid heat conduction and thus a choice can be made to locate the thermocouple immediately at the discharge or on the surface of the pump housing or side plates.

In the case of progressive cavity (PC) pumps, you have an excellent insulator between the explosives and the outer casing that reduces the effectiveness of the protection if the thermocouple is located directly on the outside surface of the housing. As a result, the location of the thermocouple (T/C) is often immediately at the pump discharge, but no more than 2 inches (5 cm) from the end of the rotor. Many explosives manufacturers have located the T/C directly in the pump stator elastomer approximately two thirds to three quarters of the way along its length. Alternatively, thermocouples have been placed at the inlet and outlet with the differential temperature being measured to shut down the pump at a predetermined temperature difference. (See Section 10.3.2 h) for PC pump thermal hazards.)

Energy, torque and speed limiters should be chosen to limit energy and force inputs to a pump in accordance with the design limits in place at the time of a hazard analysis of the pump and proposed pumping system. It is common with hydraulic or air-driven motors to select a motor with inherent limited horsepower and speed in order to avoid the need for mechanical or electrical control devices. Manufacturers' recommendations for the drive system should be followed and spare parts must be the full equivalent of the originally specified components.

Counters or timers commonly used to meter explosives into boreholes are useful in calibration to detect pump wear, especially with gear pumps, and thus can be part of a preventive maintenance program. One rule of thumb is to replace or rebuild a pump when it has lost 20% of its new pump output. Linked to a shut-down switch, they are also safety devices because they limit the duration of pumping in a no-flow or low-flow situation that may have escaped other means of observation or shut-down. Counters or reset timers are recommended for all PC pumps loading boreholes. Some in industry believe that a reset counter or timer with a cut-out switch is essential on all pumps for borehole loading.

Power systems, be they pneumatic or hydraulic, can leak through control valves and lead to the uncontrolled operation of a motor and pump. One can alleviate the problem by installing by-pass hydraulic valves (normally open) in the system to ensure any leakage will return to the tank instead of powering the pump. One manufacturer recommends this for PC pump systems as an added redundant pressure-relief mechanism.

Low-powered radio frequency (RF) devices are being used more frequently in conjunction with the pumping of explosives and other detection devices, primarily for, but not limited to, mobile pumping units. In such cases, the RF signal interfaces with other components via an output electrical signal that often works in conjunction with pneumatic pilots to control hydraulic functions.

Of concern is RF interference having an impact on an electric detonator bridge wire with sufficient energy to cause initiation at, or above, the no-fire level of 40 milliwatts for commercial detonators (reference: Institute of Makers of Explosives (IME) publication #20, *Safety Guide for the Prevention of Radio Frequency Radiation Hazards in the Use of Commercial Electric Detonators*). A potential hazard may be present when electric detonators are in close proximity to the emitting RF field source, whether temporarily stored or used. Often the low transmission power and low-frequency RF field are not adequately covered in the referenced IME document #20, but as most who are in this occupation will attest to, the available radiated energy is reduced by the distance from the source, characteristics of the transmission medium, and the efficiency of the signal-intercepting antenna. To ensure this radiation hazard does not pose a potential problem in the presence of electric detonators, one should consider quantifying the above characteristics via test results and/or calculations, all as part of a hazard review.

The same concerns may hold true as well for the newer high-precision electronic detonators where the electromagnetic characteristics need to be well defined.

11.2 COMMENTS ABOUT INSTRUMENTATION

Flow detectors with respect to "no-flow" conditions including deadheading:

Having the pump running while there is no flow of explosives running through it is the most important condition against which to provide protection. If a completely satisfactory flow meter is available, that is the best instrument. "No-flow" can also be guarded against by:

i) Too high or too low an output pressure. A relief valve or a pressure trip functioning outside a predetermined pressure range should be installed rather than relying on the operator to read the pressure gauge and turn the motor off. A system with a low-pressure stop switch must have provision for start-up.

ii) Too low a level in the feed hopper. This must be noticed by the operator if the hopper is not fitted with a low-level switch to stop the pump. A high-level feed hopper switch is recommended to prevent unnecessary overflows.

iii) A system as described in Section 11.1.

Pressure sensor devices and pressure switches are part of a redundant system and are not a total "fail safe" system. They require periodic maintenance on a regular basis. In the case of PC pumps, it is highly likely that a pressure trip will not work as intended if the stator is worn - see Section 10.3.2 h) for this important unique product-heating mechanism when deadheading occurs.

A rupture disc on the pump outlet can be an effective backup that is generally considered a quenching device, halting a deflagration through a rapid reduction in pressure. It must be recognized that these are dead-end appendages and can only be effective if the line to the disc is cleaned often enough to be free of crystallized explosives or other obstruction. How often it should be cleaned will depend on the explosives and the system. The pumping of blends or aluminized products will require more frequent maintenance. If there are no periodic inspections, all water-based explosives will crystallize sooner or later . . . some over night, some after a week. The associated rupture disc(s) will then be ineffective.

Standard bursting discs are made to rupture within plus or minus 10% of their designed pressure. When ordering a disc for a specific application, the operation temperature must also be specified. Graphite discs are recommended since their bursting pressure is much less affected by temperature and the number of load cycles, both of which cause fatigue.

The normal bursting pressure should be chosen equal to the maximum safe pumping pressure minus bursting tolerance.

When experimental data are not available, the rate of gas generated from a burning reaction to be quenched must be assumed to be high and, therefore, the line leading to the rupture disc should be at least 50 mm in diameter and the bursting disc should be at least 40 mm. The latter should be positioned immediately after the pump outlet and there should be no hindrance to flow such as elbows or material build-up before it. See also Section 11.1 under Rupture Discs.

Thermocouples and thermofuses: Most pumps will heat up if the drive continues with no flow of product. If a no-flow condition arises, a thermofuse, i.e., relief passages with a plug of material that melts at a prescribed temperature, or a thermocouple with a high temperature shut-down, or a fusibly linked rotor, will provide late protection. Ideally, every pump should have protection against high temperature right in the pump, and all pumps for which this is practical should be appropriately instrumented. A temperature cut-out activated by a sensor right in the pump or in the process lines immediately following the pump should be set at about 10-12°C above the operating temperature. Under no circumstances should it be higher than 100-110°C, which is about 10-20°C below the point where water is driven off the explosives.

All critical trips must be hardwired to shut down the pump.

Counters should not be used as the sole indicator for maintenance and rebuild needs. Counters can, however, be used in conjunction with other instrumentation to prevent pump failure or potentially dangerous situations.

11.2.1 Excessive Energy Input

Too high an energy input can be avoided by one or more devices instrumented so as to stop the pump drive if some predetermined criteria are exceeded. Some of the devices and criteria are:

- Electric current flow;
- Hydraulic flow or pressure;
- A torque limiter employing a slipping clutch or other device;
- Rotational speed; or
- A timing device.

If excessive energy input causes a temperature rise in the explosives discharging from the pump, thermocouples can be used to activate a switch to stop the pump motor or a thermoplug may be used to vent the pump itself, but recognize that it will not stop the pump. In particular, it is important to have a temperature trip or a temperature sensor with an alarm if the product is being re-circulated.

Under normal operating conditions, torque limitations may be practical to stall the pump if foreign objects should enter the pump intake housing. One company has pointed out that cold starts are almost impossible with torque limiters installed on PC pumps; other protection must be used.

11.3 FACTORY OPERATIONS (FIXED INSTALLATIONS)

NOTE: See Section 11.6 for Summary.

In general for fixed installations, there must be at least two independent safety devices, one of them being a no-flow trip. Redundancy in protective systems against no-flow is strongly recommended with particular emphasis on PC pumps. Diaphragm pump systems and other positive displacement pumps pumping through unrestricted lines may require less instrumentation. A decision can only be based on a hazard analysis, which may include testing by starving the feed (run dry) or deadheading the downstream line and operating the pump at the intended operating speed.

If the pump being instrumented is a positive displacement pump, a practical system is a high-temperature trip and a high/low-pressure trip that shuts the pump down.

A rupture disc is generally considered to be a quenching device (see Section 11.2) and is thus recommended by many as a secondary precaution for fixed installations for all positive displacement pumps and as a must requirement if pumping detonator-sensitive products - see Section 10.3.3 g).

PC pumps present a unique hazard when a worn stator develops - see Section 10.3.2 h). To guard against a relatively low pressure rise when the pump is deadheaded and in a no-flow situation requires a no-flow switch downstream of the pump or a high-temperature thermocouple (T/C) cut-out located in the pump stator itself or a differential T/C on either end of the pump - see Section 10.3.3 o).

11.4 FIELD OPERATIONS ON SURFACE

> **NOTE:** See Section 11.6 for an Instrumentation Summary and Appendix V for an approach taken by a committee on instrumentation by pump type that links precautions with identified hazards.

There has, in the past, been a considerable range of opinions about how much instrumentation is required on mobile manufacturing vehicles when an operator is continuously monitoring the pump and hose, such as in open-pit and quarry borehole loading. There are still differences of opinion but the differences seem to be narrowing. The following recommendations are minimal but **some may feel that more instrumentation is of value (see Appendix V).**

i) If an *operator is attending and sensing the pumping action* via monitoring the hose, there should be at least one device such as a reset timer (about 3 minutes*); a pressure, temperature or flow switch shut-down; a revolution countdown counter; or a tank low-level trip. There should be a temperature and pressure gauge (a useful device for all pumping applications) installed so that the operator can monitor whether a pending out-of-limits condition is developing before it actually occurs. If that is not possible, then one needs two independent cut-out instruments, particularly if a PC pump is being used. Most industry representatives believe that a temperature gauge is not needed for an air diaphragm pump.

ii) If an operator is not constantly attending and sensing the pumping action but is monitoring from inside the truck cab, there should be two independent instruments such as a pressure (low and high), temperature, hopper level, or flow monitoring to shut off the pump if an out-of-limits condition is detected. Some industry representatives recommend that one of these be a reset timer. If a PC pump is being used, then two independent cut-out (automatic trip) instruments should be incorporated in the system with one of them accounting for a no-flow situation. Additionally, a back-up rupture disc is recommended.

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* Note: If a reset timer is used, the time should be based on experimental evidence of the time to heat the given product in the operating conditions being considered in order to ensure critical temperatures are not reached, thus ensuring a safe operation.

Where low-energy, low-frequency RF devices are employed, one should consider the RF field strength in close proximity to electric detonators (see Section 11.1, Low-Powered Radio Frequency (RF) Devices).

A water spray ring via a water annulus in the discharge line may be a requirement in some applications to reduce pressures and facilitate loading.

The field operation of **transferring explosives** from one vessel to another is one that operators are tempted to leave unattended for a while. Transfer pumps using PC positive displacement pumps should be protected as adequately as borehole loading systems described in Section 11.4 ii) in the event of an out-of-limits condition, even under the favourable conditions of short, large-diameter lines. Instruments for other pumps should be developed in accordance with their potential for self heating when deadheaded or running dry. See comments in Sections 11.1 and 11.2, fifth paragraph, on rupture discs as a back-up. For other pumps in general, see Section 11.0, and see Section 10 for a particular pump type, with emphasis on thermal event protection.

Despite a strong recommendation that there be no valving downstream of pumps, it is recognized that plumbing on the discharge side of many newer vehicle installations is becoming more complicated and includes appendages that are controlled by air actuation rather than manually operated. In many installations, such valving is included upstream of the pump as well. As a result, it is imperative that protection against an accidental closure of valves controlled by air-actuated solenoid switches be provided, i.e., fail in the normally open position so that the hydraulic flow to the pump shuts off under loss of air conditions, thus preventing deadheading or starving of the pump.

11.5 FIELD OPERATIONS UNDERGROUND

NOTE: See Section 11.6 for an Instrumentation Summary.

Pumping pressures underground are typically higher than in surface operations because one is pumping through smaller-diameter hoses into down-holes as well as generally pumping a higher-viscosity product into up-holes. As a result, three- or four-stage progressive cavity pumps are often in use.

It follows that underground PC positive displacement pumps need a higher level of protection than surface field pumps, whether operated by the explosives manufacturer or the mine blasting crew, and thus factory instrumentation should seriously be considered. Redundant shutdown protection against no-flow and thermal events is essential - see Section 10.3.2 h). A well-maintained rupture disc may be of some benefit as a back-up (see Sections 11.1 and 11.2, fifth paragraph). Instrumentation for other pumps should be developed in accordance with their potential for self-heating when deadheading or running dry.

Potable water is recommended as the base fluid for water annulus mixtures as contaminated mine water (non-potable) may react with the explosives.

Screens are recommended over the explosive bins to prevent fallen rock (loose) from entering the bins and working their way into the pump. In most situations, screens should not be installed directly at the pump intake, particularly for PC pumps, as the screens will plug readily, starving the pump and leading to cavitation and the potential for a high-temperature condition. In this situation, the risks of a screen will likely outweigh the benefits (see Section 6.6, first paragraph).

Progressive cavity pumps that are used to pump explosives into boreholes have sometimes been used in reverse as transfer pumps - see comments in Section 9.3 b) regarding the use of progressive cavity pumps in reverse. The high-temperature trip will only be effective if the sensors are in the pump. In general, the sensors are at the pump outlet which, with the pump in reverse, becomes the pump inlet. The high-temperature trips are then useless.

Recent advances in technology have led to the development of radio remote-controlled pumping systems to which one needs to consider the implications of RF energy in the presence of electric and the newer electronic detonators when conducting a formal hazard review (see Section 11.1, Low-Powered Radio Frequency (RF) Devices).

11.6 INSTRUMENTATION SUMMARY

The question of instrumentation is complicated and it has been thought worthwhile to introduce two summaries that may be helpful. Others may feel that more instrumentation is beneficial (see Section 11.3):

- The first (Section 11.6.1) is a summary of instrumentation according to the type of pumping operation. It is intended as a "code of practice" based on best engineering practices and the experience of industry.
- The second (Section 11.6.2) is a summary of protective devices and the hazards that they guard against. **These summaries supplement but do not replace the foregoing sections 11 through 11.5**.

11.6.1 Summary of Instrumentation Options for Different Operations

> **NOTE:** More instrumentation may be beneficial.

A) FACTORY OPERATIONS (FIXED INSTALLATIONS)

- There must be at least **two** independent safety devices, one of them being a no-flow shutdown (S/D). A practical system is a high-temperature trip plus a high/low-pressure trip.
- Additionally, preference for a T/C to measure the internal pump temperature provides late S/D protection and is generally recommended for fixed installations regardless of pump type.
- Redundancy against no-flow is strongly recommended with emphasis on PC pumps. Additional examples are:

  - low-level hopper S/D;
  - flow monitoring;
  - timer;
  - internal pump thermocouple (T/C);
  - T/C at bearings /seals;
  - differential T/C at each end of pump.

- A rupture disc or thermofuse is required as a secondary back-up and is strongly recommended for detonator-sensitive explosives.

- Any air-actuated valves downstream of an explosives pumping system should fail in a **normally open** position under loss of air. Additionally, failed air pressure should trigger pump shut-down.

- Diaphragm pump systems and other positive displacement pumps, e.g., gear pumps pumping through unrestricted lines, may require less instrumentation. The decision should be based on hazard analysis.

B) FIELD OPERATIONS - SURFACE

B1) For Bulk Truck: *(see Section 11.4)*

i) Operator(s) is attending and sensing the pumping action (hose and surge hopper). This is generally a two-person operation:

- There should be at least **one** device designed to automatically shut down the pump:

  - a reset timer;
  - a high-pressure trip;
  - a temperature trip;
  - a revolution countdown counter;
  - a tank low-level trip; or
  - a flow switch shut-down.

- Plus temperature and pressure monitoring gauges.

- A water spray annulus is recommended in the discharge line to reduce pressure and facilitate loading in most cases.

- Consider RF field strength where low-frequency RF devices are employed to operate the pump.

ii) Operator is **not** constantly attending and sensing the pumping action but monitoring from inside the cab to shut off the pump if an out-of-limits condition is detected. This is generally a one-person operation - see Section 11.4 ii).

- There should be **two** independent instruments to automatically shut down the pump, e.g.:

  - pressure (low and high);
  - temperature;
  - reset timer;
  - low-level hopper shut-down; or
  - flow monitoring.

- If a PC pump, there should be **two** independent auto S/D instruments, one of them a no-flow S/D, e.g.:

  - pressure (low and high) and temperature; or
  - low-hopper level, high pressure and temperature.

- A rupture disc is recommended as a secondary back-up.

- A water spray annulus is recommended in the discharge line to reduce pressure and facilitate loading.

- Any air-actuated valves downstream of an explosives pumping system should fail in a **normally open** position under loss of air. Additionally, failed air pressure should trigger pump shut-down.

B2) *For Transfer Operations (Note: operators tempted to leave unattended for a while)*:

- If a PC pump, there should be **two** independent instruments, one of them a no-flow automatic S/D, e.g.:

  - pressure (low and high) and temperature;
  - reset timer;

  OR

  - low hopper level, high pressure and temperature;
  - reset timer.

- A rupture disc is recommended.

- Other pumps (e.g., diaphragm and gear) should be instrumented in accordance with their potential for self-heating when deadheaded or running dry.

C) FIELD OPERATIONS – UNDERGROUND

- Redundant protection against no-flow and thermal events is essential for many pump types. See Factory Operations for appropriate instrumentation. The decision should be based on a hazard review, taking into consideration the working environment.

- A well-maintained rupture disc is required for PC pumps and may be of some benefit as a back-up for other pump types.

11.6.2 Summary of Protective Devices and the Hazards That They Guard Against

This good tabular summary was taken from the literature of an equipment supplier and added to by the inclusion of high-temperature switches, revolution countdown counters and thermo-fuses.

Each device is an integral part of the pump safety system. They each must be properly maintained and regularly checked for correct operation.

Device	Protection	Hazard
Flow switch	Loss of flow	Running dry
Low pressure switch	Loss of flow	Running dry
High pressure switch	Excessive pressure	Dead headed
Rupture disc	Excessive pressure	Dead headed
Timer or revolution countdown counter	Unattended running	Heat build-up
Relief valve	Torque limiting	Heat build-up
High temperature switch	Deadheading or low flow	Heat build-up
Thermofuses and/or fusibly linked rotors	Deadheading or low flow	Heat build-up

12. Process Hazard Analysis

Different explosives have different sensitivities and pumps, and the explosives they move should therefore be considered as one. As a result, a process hazard analysis must be conducted for each pumping system design and reviewed periodically, about every three years. A system of change notices should be established so that no equipment or operating changes are introduced without consideration and supervisory approval. All changes that may impinge on safety should be subjected to a hazard review before implementation.

The process hazard analysis should consider at least the following aspects of the operation:

a) Nature of the product being pumped.
b) Conditions at the pump inlet and outlet.
c) The pump and the power source.
d) Pump controls, including speed, pressure, temperature and flow.
e) Environment around the pump.
f) Instrumentation.
g) Operator and operating procedures.

The hazard review team should address at least certain potentials for excess energy or energy concentration, as well as certain compatibility considerations and unsafe situations that must be avoided such as:

a) Product confinement.
b) Pump torque.
c) Internal or discharge pressure.
d) Friction.
e) High product temperature.
f) Impact (particularly metal to metal).
g) Compatibility of construction materials, including lubricants and the product being pumped.
h) Compatibility of the electrical classifications and the environment of use.
i) Compatibility of the product sensitivity and the pump proposed for the particular application being assessed for safety.
j) Voids or cracks in metal components.
k) Product contamination by tramp metal, dirt or grit.
l) Kinetic energy.

As hazard reviewing is a difficult skill, any company that does not have the skill in-house should employ consultants for reviews or to train company personnel.

13. Training

All operations using, repairing, maintaining or modifying pumps used with water-based explosives must train and re-train operating personnel in accordance with standard operating procedures. The basic steps to follow are:

a) Identify the required skills for the job.

b) Determine whether the company has the necessary “doing” and teaching skills within its employees. If necessary, hire a consultant.

c) Develop training schedules. There should be a separate training program for each type of pump and each required skill should have its own training module.

d) For each employee, develop a training plan and establish a file to track training.

e) Ensure that there is an operating manual for each pump and auxiliary equipment covering each pump application, plus a log book for each pump.

f) Training should include both classroom and practical work with an experienced operator. It should include but is not limited to the following:

- Familiarization with the operating manual and pump manufacturer’s manual is essential. If available, models, cut-aways, drawings and flow diagrams of the pump and piping assembly are very helpful.

- Short video presentations can show pump types and scenarios demonstrating what to do in the event of a pump malfunction. Videos can also show the effects on products being pumped when pumps fail to function properly.

- Videos and written material, such as incident reports, can be used to show and emphasize that most fires and explosions associated with water-based explosives operations have originated in pumps, either through pump failure or poor operating procedures.

- The ignition, burning, transition to detonation, and direct initiation to detonation of water-based explosives should be described and the properties of the explosives relating to ignition or initiation by friction, impact or heat should be addressed.

- The practical or “hands on” training should cover normal operations, plus dismantling, inspecting and servicing the pump under review. Procedures for establishing calibration benchmarks for pump operation to be used in troubleshooting and the functioning of instrumentation and interlocks should also be covered. The maintenance of log books and the reporting of incidents must also be covered.

The usefulness of other training aids should not be overlooked in drawing up a training schedule, which may require chalkboards, overhead projectors, slide projectors, safety videos, motion pictures and training binders.

g) Persons who have been through the training program for a pumping system should be allowed to become operators only after obtaining a satisfactory mark in an examination that should be in part written and in part practical.

h) Persons who have received a satisfactory mark should receive certificates and have this noted in their files.

i) Operators should be retrained periodically, at least every two years or whenever there is any change in the system they are operating.

j) In addition to a retraining program, any company that employs pumps for explosives should conduct periodic discussions on the safe pumping of water-based explosives at least every quarter.

14. General Safety Procedures

Personnel operating pumping equipment should understand and practise standard operating safety procedures before the equipment is put into operation.

A formal training and retraining program addressing personal safety, explosives materials handling, operating procedures and equipment must be instituted and maintained.

Personnel working around bulk loading equipment should wear safety glasses or safety goggles and safety shoes at all times. Dust respirators should be worn while loading or unloading AN prills. Hard hats should always be worn when working around equipment where items could fall or a head bump hazard exists.

Clothing that covers the arms and legs should be worn when pumping from a bulk truck.

Loose clothing, necklaces, chains, bracelets or rings must not be worn when operating or working around bulk loading equipment or factory cartridging operations.

Gloves should be worn when hand contact with materials used in explosives formulation cannot be avoided. If contact causes a rash or dermatitis, consult a doctor.

Open cuts should be protected to prevent contact with explosives or their ingredients.

Contact with explosives materials or ingredients, especially prolonged contact, may cause a stinging sensation, burning or dermatitis. **Consult the material safety data sheets (MSDS) for the materials involved.**

Explosives or ingredient contact with eyes may be injurious whether or not there is any immediate burning or discomfort. Flush the eyes with water for at least 15 minutes and consult a doctor immediately.

Ingestion of explosives or their ingredients may be injurious whether or not nausea or other symptoms are experienced. Consult a doctor immediately.

Contaminated clothing could be a fire hazard or could cause dermatitis through prolonged contact. Contaminated clothing should be removed and cleaned before reusing.

Spills should be cleaned up immediately, especially on ladders and in walking areas as products are often slippery. Spills must be disposed of according to established procedures that take into account environmental regulations related to explosives safety. To deal with large spills of ingredients, consult the manufacturer.

Guards must be in place over rotating joints.

Augers are often used in the field in conjunction with pumping systems. Clean-out doors must be closed and latched before starting augers. Power take-off must be disengaged before any attempt is made to clean out jammed augers or make any repairs to augers. Check for snags or burrs on the ends of auger flights. Repair augers before starting operation. Clear personnel away from augers before starting operation. Augers should be washed or steam cleaned before repairs or any hot work of any description are carried out. The design of hollow auger shafts, primarily found in mobile equipment, should allow for easy dismantling in the field and steam flushing of the internal drive tube. Operators must be aware of how to conduct this decontamination procedure prior to doing any hot work repairs.

Lock-out and tag-out procedures must be followed when performing maintenance.

Make a visual check of hydraulic motor mounts and pump mounts.

Visually check the condition of hoses. Replace worn or damaged hoses immediately. Avoid pinch points around the hose reel.

Visually check the high-pressure rupture disc. Make sure that the proper disc is in place and that the rupture disc vent pipe is clear and open.

Never disconnect any type of alarm and never by-pass any safety device on a pumping system. Upon activation of an alarm, pumping operations must be shut down and not resumed until the problem has been corrected.

Packing glands are best never used but, if they are, never over-tighten the packing nut.

Observe the site or factory rules with regard to smoking, matches, flame-producing devices, open flames, firearms and ammunition.

In making repairs or doing maintenance on bulk trucks, operators should follow prescribed safety procedures.

All pumps for explosives and associated piping must be disassembled and cleaned before making major repairs. If there are hard-to-clean pockets, threads or other semi-confined zones, decontamination may be necessary before disassembly. Decontamination should only be done after consultation with an experienced and knowledgeable person using approved procedures.

No hot work of any kind is to be done on any pump or associated equipment, or on the vehicle on which the pump may be mounted, until all oxidizing materials, fuels and explosive materials have been removed and the equipment has been thoroughly cleaned by washing down or steam cleaning. The effluent from wash-down must meet environmental regulations or be treated or shipped out for treatment before discharge to the environment.

The outside of a bulk truck should be cleaned before minor repairs or routine maintenance are carried out.

15. Maintenance Procedures and Checklist

A maintenance schedule and the keeping of maintenance records must be established for each pump, and establishing familiarity with them and emphasizing the need for following them should be part of every training program.

Maintenance schedules should be those recommended by the explosives manufacturer, who should have consulted the pump manufacturer.

In the absence of other information, the chart in Appendix I may be used initially to establish the frequency of preventive maintenance procedures for a pumping system.

A log book should travel with each pump for recording rebuilds, problems, etc., and maintenance records should be used to verify or modify maintenance schedules.

Some form of totalizer, be it pump revolutions or pounds pumped, should be used as a tool to help observe the preventive maintenance and service schedule.

Only hand-operated grease guns should be used for lubricating pumps.

The ISO Quality Management System Standards have become internationally accepted as the way to manage quality assurance. In managing maintenance, the responsible managers might well benefit from a paper presented to the 1997 Canadian Institute of Mining (CIM) at its 1997 Annual General Meeting. The title and author are: *Managing Maintenance in the 21st Century* by Ken Musgrave. Although it is written for a base-metal mining operation, it describes the structure and steps required to implement it, which could readily be transferred to the explosives industry.

The CIM article mentioned above includes Appendix VI, which illustrates a cross-reference between ISO 9001 and the Maintenance Management System (MMS) Standard, which uses the same element numbers but is reworded appropriately for a maintenance application.

16. Appendices

Appendix I is a provisional maintenance checklist.

Appendix II is a troubleshooting checklist.

Appendix III is a write-up on safety philosophy by the Federation of European Explosives Manufacturers.

Appendix IV is a suggested form for reporting pump incidents for circulation to industry.

Appendix V is an approach taken by a committee on instrumentation. It shows how to systematize thinking to link precautions with identified hazards.

Appendix VI is an ISO approach to maintenance.

Appendix I

FREQUENCY OF MAINTENANCE

	Daily	Weekly	One Month	Three Months	Six Months	One Year	Two Year
Product pump				X	X		
Coupling spiders	X						
Hose blowdown	X						
Auger cross bolts	X						
Pressure sensor						X	
Pressure switch			X				
Low suction alarm						X	
Spray ring pump		X					
Hose reel		X					
Hydraulic tank	X						
Hydraulic line and valve	X						
Product tank	X	X	X			X	X
Fire extinguisher			X				
Suction piping to pump		X					
D.O.T. valve	X						
Air tank (drain) on air system			X				
Pump suction chamber					X		
Discharge hose	X	X	X				
Rupture disc	X	X	X				

In the absence of other information, this chart may be used initially to establish the frequency of preventive maintenance procedures for a pumping system.

Appendix II

Pump will not start	Pump will not prime	Low product rate	High discharge pressure	Pump delivery irregular	Pump operates noisily	Pump has seized/stopped delivery	Stators or gears wearing	Spray ring pump inoperable	Low-suction warning on	High-pressure warning on	Hose reel inoperable (down)	Hose reel inoperable	High pressure	Tachometer and totalizer	
x		x													Pump malfunctioning
x															Pressure between stator and rotor too great
x															PTO not engaged
	x								x						Product tank valve closed
				x	x										Product level in tank low or empty
			x										x		Spray ring system malfunctioning
			x					x							Check water supply tank level
x			x				x			x			x		Product hose plugged
													x		Discharge valve not fully opened
x						x					x	x			Hydraulic system malfunction
x															Low hydraulic oil
x		x									x	x			Low hydraulic pump pressure
x									x		x	x			Hydraulic valve oil leak
x									x		x	x			Failed hydraulic control valve
x									x		x	x			Hydraulic motor coupling broken
											x	x			Hose reel drive chain broken
			x	x											Component speed adjustment wrong
											x				Sensor out of adjustment
										x					Pressure switch out of adjustment
										x	x			x	Electric system problem
														x	Dirty terminal blocks
														x	Broken or shorted wires to transducer
														x	Transducer out of adjustment
x														x	Faulty electric relay
x	x														Pump direction reversed
					x										Coupling joints, drive shaft worn
x					x	x	x								Foreign material in pump
					x										Coupling rods and pins lack clearance
x					x										Pump misaligned
x															Keys sheared or missing
		x						x							Suction line or shaft seal leaking

Appendix III

SAFETY PHILOSOPHY

Traditionally, hazards in handling conventional explosives have been associated with the presence and type of explosive sensitizer (nitroglycerine, TNT, etc.) and the presence of grit or such friction/impacting particles acting as sensitizing centres.

With the newer technology of water-based explosives, this hazard pattern has been dramatically changed in that the main hazard component, the explosive sensitizer, has been removed.

It must, however, never be forgotten that, whilst the sensitizing mechanism to detonation may be different, the ultimate result of that detonation is just as devastating with water-based explosives as with the traditional types. The recognition of this fact has led to a school of thought that the same manufacturing techniques and precautions as are applied in the nitroglycerine explosive technology should continue to be applied to watergel/emulsion technology. It is the Federation of European Explosive Manufacturers' contention that, whilst this is arguable, it is not necessary to adopt quite such an extreme position provided that there is a clear understanding of the causes of accidents, that these causes are properly analyzed, and that each factor is given its proper place in safety evaluation.

In most accident investigations, a single cause is sought. However, the reality of the situation is that, more often than not, many factors (mechanical, physical, chemical and psychological) are linked in a complicated pattern leading to an accidental explosion. To assemble these factors in a manner that allows interpretation is complex. For present purposes it is sufficient to consider that the safety regime in which any explosive is manufactured is governed by the tolerance of that explosive to cope with a number of combining adverse technical and human factors - factors which, if encountered singly, would be well within the safety regime of the explosive. With each explosive there is, however, a point reached where a combination of such factors stresses the safety tolerance of the explosive beyond its limits, which results in an unintentional initiation and accident. This "critical stress level" varies from explosive to explosive but the factors involved are common to all.

Human Factors Involved in "Hazard Stress"

Risk consciousness
Management style
Supervision
Auditing and control
Information and training
Production rate - remuneration system
Personal relations in working teams
Housekeeping
Negligence, carelessness
Violation of rules
Ignorance, mistakes
Physical or mental insufficiency
Acute illness
Alcohol, drugs

Technical Factors Involved in "Hazard Stress"

Design and construction of processing equipment
Malfunction of machinery and instruments
Maintenance
Pressure, temperature and velocity gradients
Friction, impact, air bubbles
Grit and foreign bodies
Static electricity
Atmospheric conditions
Compositional changes
Changes in raw materials
Chemical stability
Pump type
Inadequate working instructions
Wrong or defective tools
Job environment

It is the Federation of European Explosive Manufacturers' opinion that, whilst most companies have an orderly regime in which all of these factors are considered, they can, in certain circumstances, become additive and influence the total "stress level." Normal operations work well within the critical stress level but, occasionally, a number of factors can coincide and the total stress then exceeds the critical level and an accident occurs.

With the introduction of water-based explosives, the critical stress level/tolerance has been significantly improved. These explosives can withstand very high mechanical loads and, as a consequence, should afford a very high standard of safety in manufacture. Unfortunately, this has not proven to be the case. It is the Federation of European Explosive Manufacturers' opinion that this is due to the changing attitude towards the factors involved in safety.

One factor at least, that of "risk consciousness," has materially decreased. In laboratories it has been shown that the new explosives can withstand almost any mechanical load. In practice, advantage is taken of this fact and, consequently, production pressure, temperature and velocity gradients are increased and manufacturing methods are introduced that can and have led to unacceptable temperature rises resulting in decomposition, deflagration and detonation. This means that the work is carried out at a hazard stress level substantially above that for conventional explosives. This practice is acceptable provided that the safety regime is still below the critical stress level for water-based explosives.

It is contended that, with the improvement in inherent safety, there is little doubt that, provided the safety regimes and regulations applicable to conventional N/G explosives are applied, accidental explosion during manufacture would be virtually eliminated. The benefit of the greater inherent safety in manufacturing techniques can result in a laxity in safety approach on the part of both management and operators, which all too often negates this advantage. This tendency can lead to a combination of safety failures that exceeds the critical stress level of even these inherently safe compositions and an accident occurs.

Acknowledgement:

Federation of European Explosive Manufacturers, *Code of Good Practice on Safey of Machine Design in the Processing of Emulsions and Water-Gels* (Publication No. 18).

Appendix IV

PUMP INCIDENT REPORT

COMPANY: ______________________ PARENT COMPANY: ______________________

LOCATION: ______________________ LOCATION: ______________________

DATE: ______________________

OPERATOR(S): ______________________

INCIDENT DESCRIPTION (include time and place of occurence and what happened):

____

____

PRODUCT INFORMATION (indicate units)

Name of product: ______________________ Temperature: ______________________

Sensitization: Yes ☐ No ☐ Density: ______________________

Type: ______________________

Water content (%): ______________________ Viscosity at: ______________________

PUMP INFORMATION (indicate units)

Type of pump: ____________ Model: ____________ Number of stages: ____________

Discharge pressure: ____________ Pumping rate: ____________

Application: ____________

Rupture disk: Yes ☐ No ☐ Type: ____________ Setting: ____________

Water injection: ____________

Discharge hose type: ____________ Hose length: ____________ Hose diameter: ____________

Shut-down system (describe): ______________________

Date pump installed: ____________ Estimated throughput: ____________

Date of last maintenance: ____________

Describe: ______________________

Completed by: ____________ Position: ____________

Address: ______________________

Date: ____________ Phone: ____________ Fax: ____________

Corrective action taken: ______________________

Appendix V

Pump Type	Unsafe Condition	Recommended Safeguard
Progressive cavity	Dry pumping	Trained operator present, pressure gauge easily seen by operator, and one redundant safety. Redundant safety options include: low pressure trip, timer trip, flow trip, thermocouple trip or thermofuse; and two independent safeties (i.e., pressure gauge cannot be sensed with pressure trip).
	Deadhead pumping	Trained operator present, pressure gauge easily seen by operator, regular calibration to indicate slippage, and one redundant safety. Redundant safety options based on the explosives manufacturer's specification include: a rupture disc rated below the deadhead pressure, high pressure trip, torque limiting device, thermofuse or no-flow trip; and two independent safeties.
	Foreign object	No mandatory safety. A screen is to be sized to explosives manufacturer's specification.
	Cavitation	To be avoided through pumping system design. Considerations should include pump speed, suction side configuration, product viscosity, and leakage. Cannot define minimum standard since difficult to measure.
	Friction	To be avoided through pumping system design. Packing glands are not recommended.
	Excessive speed	Maximum pump speed to be specified by the explosives manufacturer with recognition that higher energy input accelerates the effects of cavitation, impact, friction, deadhead and dry running. Motor, valve and power settings to be specified by the explosives manufacturer to ensure the pump does not exceed the maximum recommended speed.
	Pump slippage	Test through pump calibration (see deadhead pumping).
	Product accumulation	To be minimized and covered by each explosives manufacturer.
	Loosening of retaining nut and bolts	Hazard to be reviewed by explosives manufacturer and tested through maintenance.
	Seal failure	Hazard to be reviewed by explosives manufacturer and tested through maintenance.

Pump Type	Unsafe Condition	Recommended Safeguard
Gear and lobe	Friction	Gears are to be covered with rubber. Not recommended for use with emulsion blends with ammonium nitrate prill or similarly abrasive solids. Side plate friction to be examined by explosives manufacturer.
	Bushings and bearings	Outboard bearings to be used to avoid leakage into bearings. No brass.
	Dry pumping	Explosives manufacturer to specify safeguards.
	Deadhead pumping	One safety based on the explosives manufacturer's specification. Options include: a rupture disc rated below the deadhead pressure, high pressure trip, torque limiting device, thermofuse or no-flow trip; and calibration tests to be used to guard against wear and to maintain the pressure limit above any pressure-related safety device.
	Foreign object	No mandatory safety. A screen is to be sized to explosives manufacturer's specification.
	Cavitation	To be avoided through pumping system design. Considerations should include pump speed, suction side configuration, product viscosity, and leakage. Cannot define minimum standard since difficult to measure.
	Friction	To be avoided through pumping system design. Packing glands are not recommended.
	Excessive speed	Maximum pump speed to be specified by the explosives manufacturer with recognition that higher energy input accelerates the effects of cavitation, impact, friction, deadhead and dry running. Motor, valve and power settings to be specified by the explosives manufacturer to ensure the pump does not exceed the maximum recommended speed.
	Pump slippage	Test through pump calibration (see deadhead pumping).
	Product accumulation	To be minimized and covered by each explosives manufacturer.
	Loosening of retaining nut and bolts	Hazard to be reviewed by explosives manufacturer and tested through maintenance.
	Seal failure	Hazard to be reviewed by explosives manufacturer and tested through maintenance.

Pump Type	Unsafe Condition	Recommended Safeguard
Piston	Dry running	Explosives manufacturer to specify acceptable pumps and safety guards. Consideration is to be given to limiting the input power, impact, heat dissipation and the product being handled. Safety options include: low pressure trip, timer trip, no-flow trip, thermocouple trip or thermofuse.
	Deadhead pumping	Pumping system to be designed to install at a pressure below the maximum pressure recommended by the explosives manufacturer for the pumping conditions and product. Explosives manufacturer to specify a system to prevent movement of the piston when product stops flowing from the pump.
	Adiabatic compression of air bubble	Explosives manufacturer to consider this aspect with respect to pumping system and product.
	Foreign object	No mandatory safety. A screen is to be sized to explosives manufacturer's specification.
	Cavitation	To be avoided through pumping system design. Considerations should include pump speed, suction side configuration, product viscosity, and leakage. Cannot define minimum standard since difficult to measure.
	Friction	To be avoided through pumping system design. Packing glands are not recommended.
	Excessive speed	Maximum pump speed to be specified by the explosives manufacturer with recognition that higher energy input accelerates the effects of cavitation, impact, friction, deadhead and dry running. Motor, valve and power settings to be specified by the explosives manufacturer to ensure the pump does not exceed the maximum recommended speed.
	Joint and/or shaft failure	Explosives manufacturer to set pump specifications and determine maintenance requirements. Joints are to be sealed.
	Pump slippage	Test through pump calibration (see deadhead pumping).
	Production accumulation	To be minimized and covered by each explosives manufacturer.
	Loosening of retaining nut and bolts	Hazard to be reviewed by explosives manufacturer and tested through maintenance. Special consideration to cover the impact of piston due to loosening of the drive rod.
	Seal failure	Hazard to be reviewed by explosives manufacturer and tested through maintenance.

Pump Type	Unsafe Condition	Recommended Safeguard
Air diaphragm	Metal-to-metal contact	(As per IME document) Limit air pressure to pump or explosives manufacturer's recommendation (the least of both).
	Failure of diaphragm	Awareness by explosives manufacturer of maintenance issues associated with non-compatible materials.
	Foreign object	No mandatory safety. A screen is to be sized to explosives manufacturers' specification.
	Cavitation	To be avoided through pumping system design. Considerations should include pump speed, suction side configuration, product viscosity, and leakage. Cannot define minimum standard since difficult to measure.
	Friction	To be avoided through pumping system design. Packing glands are not recommended.
	Pump slippage	Test through pump calibration (see deadhead pumping).
	Product accumulation	To be minimized and covered by each explosives manufacturer.
	Loosening of retaining nut and bolts	Hazard to be reviewed by explosives manufacturer and tested through maintenance.
	Seal failure	Hazard to be reviewed by explosives manufacturer and tested through maintenance.

Appendix VI

ISO 9001 and MMS* Standard Comparison

ISO 9001		MMS* Standard	
1	Scope	1	Scope
2	Normative reference	2	References
3	Definitions	3	Definitions
4	Quality system requirements	4	Quality system requirements
4.1	Management responsibility	4.1	Management responsibility
4.2	Quality system	4.2	Maintenance system
4.3	Contract review	4.3	Contract review – may not be applicable
4.4	Design control	4.4	Design control
4.5	Document and data control	4.5	Document and data control
4.6	Purchasing	4.6	Purchasing
4.7	Control of customer-supplied product	4.7	Control of customer-supplied product – not applicable
4.8	Product identification and traceability	4.8	Product identification and traceability
4.9	Process control	4.9	Maintenance control – this will be the most extensive element, covering standard practices, safety procedures and preventive maintenance
4.10	Inspectation and testing	4.10	Inspectation and testing
4.11	Control of inspection, measuring and test equipment	4.11	Control of inspection, measuring and test equipment
4.12	Inspection and test status	4.12	Inspection and test status
4.13	Control of nonconforming product	4.13	Control of nonconformance
4.14	Corrective and preventive action	4.14	Corrective and preventive action
4.15	Handling, storage, packaging, preservation and delivery	4.15	Handling, storage, packaging, preservation and delivery
4.16	Control of quality records	4.16	Control of maintenance records
4.17	Internal quality audits	4.17	Internal maintenance audits
4.18	Training	4.18	Training
4.19	Servicing	4.19	Servicing – may not be applicable
4.20	Statistical techniques	4.20	Statistical techniques – maintenance performance measurement

* Maintenance Management System (MMS) Standard.

17. Index