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TO: : FILES
THRU : Clifford K. Beck, Chief
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JAN 2 1 1960

File Standards & criteria

SUBJECT: OIL FIRES AND EXPLOSIONS IN COMPRESSED AIR SYSTEMS

References:

a) Memo from J. B. Graham (ACRS) to H. L. Price (L&R) dated 30 November 1959.

b) Office of Health and Safety Letter HS:SFP: dated 24 November 1959 to AEC Operation Offices.

c) Division of Production Letter HS:SFP: dated 20 November 1959 to Managers, Savannah River, Oak Ridge, and Hanford.

Enclosures:

A) Synopsis of Articles on Oil Fires and Explosions in Compressed Air Systems.

B) Bibliography of Articles on Compressed Air Systems.

1. As a follow up of the high pressure air flask explosion experienced at Knolls Atomic Power Laboratory on 30 October 1959 and the request made in reference (a), a review has been initiated of hazards associated with use of compressed air systems as they relate to reactor system designs and operation. This review has been directed towards establishment of the following:

   1) Whether high pressure oil/air systems similar to the Triton prototype exist on other AEC or licensed reactors.

   2) The application of compressed air systems in general in reactor plant designs.

   3) Hazards associated with use of compressed air systems.

   4) Design features that will eliminate or minimize dangers from compressed air/oil fires or explosions.

2. A review was made of plant descriptive material in the hazards reports on compressed air systems for the following major reactor plants:

N. S. Savannah
Yankee
Consolidated Edison
PWR ?
VBWR
Commonwealth Edison ?

6/9

A summary of this review is as follows:

1) Yankee Plant

Yankee has no high pressure hydraulic oil/gas systems. Low pressure (100 psig) control air and service systems are provided.

The Yankee control air system has two 120 scfm 600 rpm control air compressors with V belt drive and 25 hp motors to provide air at 100 psig to instrument and control systems. The compressors are of a non-lubricated carbon ring type. Air filters and dehydrating units are provided down stream of the air receivers.

The service air system is filled by one 514 scfm service air compressor with V belt drive and a 100 hp motor to provide 100 psig service air. The compressor is of the lubricated type. This system is interconnected and serves as standby for the control air system when control air pressure decreases to 60 psig.

2) Shippingport Pressurized Water Reactor

The PWR valve operating system uses 3000 pound air flasks to pressurize a water flask to operate the main coolant stop valves. A compressor charges the air flasks. Output of the compressor is filtered before entry to the flasks.

3000 pound air flasks also used as an emergency charging method for main coolant.

3) Vallecitos Boiling Water Reactor

The control rod drives are patterned after those used on the Borax reactors. The actuating mechanism is a double acting air cylinder with the piston attached to the drive shaft. During normal operations, air pressure is applied to the lower side of the cylinder driving the shaft up, until a stop on the shaft contacts a motor-driven stop. When the motor driven stop is moved up or down the stop on the shaft and the control rod follows it. To scram the reactor, air pressure is removed from the lower part of the cylinder and higher pressure applied to the upper part. The piston is driven down by the air pressure causing the stop on the shaft to separate from the motor driven stop. A balancing cylinder at the top of the shaft is provided with reactor pressure so that the cylinder and motor driven stop do not have to overcome reactor pressure. Normal scram pressure is 180-200 psi and normal operating pressure is 50-60 psi.

Loss of control air pressure causes the rod to scram.

Compressed air for the instrument system is provided independent from the air supply for the control rods.

The compressor is a 10 cu. ft./min. unit at 100 psig. It is equipped with coolers, a moisture separator and a 80 gallon receiver.

The control rod air supply is provided by a compressor and receiver connected to the high pressure accumulator on the control rod drive mounting. A check valve inserted in the high pressure line prevents loss of air in the accumulator in the event of a break. The compressor is a two stage receiver-mounted unit driven by a 5 hp motor. It is rated at 2 cu.ft./min. of 200 psi air. Automatic start and stop is provided.

4) Commonwealth Edison (Dresden Plant)

Control rods are mounted on the bottom of the reactor. The drive mechanism for both normal operation and scram is an all hydraulic system. Scram action is accomplished by an independent hydraulic energy source.

The drive mechanism provides normal operation and scram stroke by a conventional piston and cylinder combination, the piston and rod being connected to the poison section by a mechanical coupling. Withdrawal is accomplished with an excess of pressure on an unlocking piston and the top of the rod drive piston. Normal controlled insertion is done with an excess of pressure on the bottom of the piston rod. Scram is obtained by an excess of pressure on the bottom of the piston rod while simultaneously venting of the top of the piston rod to a scram dump tank.

Variable positioning of the rod is accomplished by directing water at 200 psi over reactor pressure to either top or bottom of the drive piston. The opposite side of the drive piston is simultaneously vented to a header held at 30 psi over reactor pressure. Rod movement is therefore obtained by the 170 psi difference in pressure on the top and bottom of the drive piston.

Reactor feed water is the basic hydraulic fluid.

The pressurizing force for scram functions is obtained from the hydraulic accumulator charged with water to 1400 psig. Details of the air pressure maintained on the air side of the accumulator pistons are not described but are thought to be in the order of 1400 psi.

Details on the compressors are not given.

5) N. S. Savannah

Hydraulic pressure required for scram is maintained in a scram accumulator. Rod Drive Mechanical Control uses a piston type hydraulic accumulator. Hydraulic pressure on the oil side of the accumulator is approximately 2800 psi during normal operation and 1100 psi on the gas side. A leak detection scheme indicates fluid leakage to the gas side. Gas used is nitrogen.

6) Consolidated Edison

The Consolidated Edison description was not complete enough to identify the details but some sort of hydraulic rod activating scheme appears contemplated. From what was described a scheme similar to N. S. Savannah appears planned.

7) Other

Projects such as PG&E and Northern States have not yet submitted detailed information on compressed air systems.

3. From this review it can be concluded that:

1) The major licensed reactor plants reviewed do not use high pressure air/oil systems.

2) Compressed air systems are being used in rod drive control schemes, for instrument and valve control and general air services. Descriptive material in the hazards reports on these systems are not complete.

4. By reference (b), the Office of Health and Safety initiated follow up action on getting a review in AEC installations for existence of systems involving mixtures of air and oil under high pressure. By reference (c), Division of Production requested Hanford, Savannah River, and Oak Ridge to submit results of findings by 15 January 1960 including emphasis on phases relating to safety of reactors and reactor appurtenances.

5. A search of the literature has been made to determine what hazards might be involved in use of compressed air systems in general, particularly low pressure systems in common use in our reactor plants. This has shown that fires and explosions are known to have occurred in compressed air systems since the earliest days of the air compressor and the subject deserves serious attention with respect to reactor plant design. A summary of pertinent articles is attached as encl. (A) and a more complete bibliography prepared by the Knolls Laboratory as encl. (B).

6. The literature reveals much to explain the phenomena and mechanisms of fires and explosions in compressed air systems. The common facts in all cases is the presence of oil in the air supply which is introduced through use of oil lubricants in the compressors. Based on this literature review a set of suggested criteria has been prepared as follows with respect to review and acceptance by HEB of compressed air systems in our licensed reactor projects:

1) Loss of compressed air should not create an unsafe plant condition. Reactor shutdown if necessary should still be possible.

2) Where vital valves or mechanisms rely on air supply for operation, more than one air compressor should be available as an air source.

3) Where air is being used as part of rod drive mechanisms control schemes, preference for non-oil lubricated compressors should be indicated.

4) Where lubricated oil compressors are used for any service associated with reactor plants, additional safeguards are required. These include:

   a) Use of fire resistant lubricants.

   b) Temperature monitoring devices on the compressors with electrical power cut offs upon abnormal temperatures.

   c) Provisions should be made for draining valleys in the air system.

5) After coolers are recommended as essential to good operation. Instrumentation should provide for compressor cut-off upon loss of cooling water to either after coolers or compressors.

6) Fusible plugs as well as thermometors should be installed closely to the outlet valves on the discharge pipes from air cylinders and intercoolers.

7) Cylinders and receivers should have provisions for periodic examinations for oil and/or carbon deposits or for periodic cleaning. Instrumentation should be provided to show at all times the internal pressure and to prevent over pressure.

8) Where high pressure gas/oil accumulators are required, the provisions of sections of air, H7.5 and H7.1.3 of IIC Hydraulic Standard for Industrial Equipment dated July 1959 are applicable. (See Encl. A).

These criteria should be considered preliminary at this point. Using them as a basis of discussion with the licensed reactor projects should reveal deficiencies that might exist in the criteria.

ENCLOSURE A

Synopsis of Articles on Oil Fires and Explosions in Compressed Air Systems

1. Reference:

"Oil Fires and Explosions in Compressed Air Systems" by A. C. Smith - Scientific Lubrication April, 1959.

(A. C. Smith - Shell Petroleum Co. Ltd.)

In this paper, A. C. Smith reports that fires and oil explosions are known to have occurred in compressed air systems since the earliest days of the air compressor and states that "Attempts to make systematic surveys of the extent of hazards have never given very comprehensive results, but there is no doubt that it deserves serious attention."

This author concludes that in explosions in compressed air systems the primary explosive medium is normally oil vapor and not oil mist or gaseous products of chemical decomposition. On this basis an explosion will normally require local temperatures in excess of the effective flash point of the oil at the operating pressure combined with favorably low rates of air flow.

The effective flash point of oils is reported not to increase very much with increase in air pressure owing to the rapid increase in vapor pressure with increase in a temperature. At 8 atm. the effective flash point of a typical compressor lubricant will be about 50°F higher than the value at atmospheric pressure. The rate of increase of the effective value with multiplication of air pressure will fall off rapidly. In any system, therefore, temperatures of the order of 50°F above the flash point of the oil are dangerous in that safety then depends on continuous dissipation of oil vapor through movement of air. This does not mean that the flash point of the oil should be as high as possible; attempts to secure safety by using heavy oils of high flash point defeat their own objective, since heavy oils are more prone to form deposits and on this account may be dangerous.

In discussing safety precautions the author concludes that "in a situation where flow hazard was absolutely prohibited, it would be necessary either to use an "oil-free" compressor or to remove the compressor altogether." With more conventional air compressor safety could be enhanced by:

1) Using lubricants with greater resistance to fire than mineral oils, taking care that other qualities required in the application are not sacrificed and no undesirable side effects are introduced, such as a toxic hazard.

2) See that air flow was maintained in the discharge system at a sufficient rate to prevent the development of an explosive concentration of combustible under all off loaded conditions.

3) Prevent development of dangerously high temperatures in the system. A limit of 150°C for discharge temperature is suggested. A maximum of 50°F above the flash point of the oil at atmospheric pressure is also suggested.

4) Good maintenance and cleaning to guard against excessive deposits.

5) Keep oil carry-over to a minimum.

6) Keep air inlet filters in effective condition.

7) Regularly inspect discharge system.

8) Avoid oils prone to deposits. This includes unnecessarily heavy oils.

2. Joint Industry Conference (JIC) - Hydraulic Standards for Industrial Equipment - July 1959.

The following excerpts were taken from these standards revised and adopted at the April 15-17, 1959 Joint Industry Conference, Detroit, Michigan.

H6.5 Accumulators

H6.5.1 - The accumulators shall be constructed to withstand at least 5 times the operating pressure of the hydraulic system it serves.

H6.5.2 - Means shall be provided for safely relieving accumulator gas and liquid pressure before accumulator can be disassembled.

H6.5.3 - Hydraulic circuits incorporating accumulators shall be arranged so that the system can be bled at the high point of the circuit.

Safety

H7.1.3

A. Hydraulic circuits incorporating accumulators shall be interlocked to vent or isolate accumulator fluid pressure when power is shut off.

B. In circuit application, where accumulator pressure is isolated, full information shall be given or near accumulator for proper servicing to prevent injury to personnel.

H7.1.4 - Gas accumulators operating above 200 psi charging pressure shall be charged with nitrogen unless fire resistant fluids are used in which case air is permissible.

3. Reference:

"Compressed Air Systems" by W. E. Bowden and R. H. Moore - Report in Canadian Mining Journal, page 73, Vol. 76, September 1955.

The authors report observations made during an extensive tour of mines in South Africa and Europe including case histories of compressed air explosions. Various regulations in the countries visited to minimize such occurrences are reviewed. The authors include a general summary of items in connection with good installation and operating practice with reciprocating compressors (mainly applicable to stationary compressors where air temperatures are over 250°F) included the following:

1) Avoid valleys in the air system. Provide means for draining valleys where they exist.

2) Intake air should be as clean and cool as possible.

3) On the compressor, there should be thermometers for measuring air temperatures after the low pressure cylinder, intercooler and high pressure cylinder.

4) Cylinder lubricated oil should be a mineral oil or napthlene base. Quantity of oil used should be kept to a minimum and oils used carefully checked with the compressor manufacturer and oil suppliers.

5) Valves, coolers, receivers and piping should be examined at regular intervals and cleaned as often as necessary to prevent any appreciable deposits of carbonaceous material from accumulating. Piston rings should be replaced as often as necessary to prevent leakage.

6) After coolers are recommended as essential to good operation.

7) Electrical power cut offs may be installed to cut off power should air temperature in the compressor rise abnormally.

4. Reference:

"The Mechanism of Explosions in Compressed Air Pipe Ranges" - R. Loison - Paper 26, UDC 541.126:621.53:633 - Published by the Safety in Mines Research Establishment, Ministry of Fuel and Power.

This paper presented in July 1952 to the Seventh International Conference of Directors of Safety in Mines Research reports on a number of experiments made by Loison to determine the phenomena association with compressed air explosions. Loison reported that the combustible elements that cause these explosion originate in the lubricating oil of the compressors which is carried along by the compressed air and deposited in the air receiver and in the piping system. Loison then conducted experiments on the action of a current of air on a deposit of oil. He confirmed that under certain conditions a deposit of oil may heat up and give off inflammable vapors which can ignite spontaneously.

Loison reported experiments in which a mass of material saturated with lubricating oil was gradually heated and over which a current of heated oxygen was passed at atmospheric pressure. When the temperature exceeded a critical value, a reaction occurred; the oil vaporized and the vapors ignited spontaneously. When the mass of material holding the oil was rust, the critical temperature for spontaneous ignition was observed to be 320°F. Loison calculated from the partial pressure of oxygen in air that similar results would occur from the substitution of air at 70 psi. This was confirmed by passing air over deposits collected from one of their compressors. The threshold of oxidation was found to be at 310°F at a pressure of 100 pounds. This process of exo-thermal reaction of oxygen on oil and carbon has also been reported by the U. S. Bureau of Mines in its report RI 4465 published in June 1959.

Loison also showed through experimentation that where the initial explosion is sufficiently severe to initiate a shock wave near or above the speed of sound, the temperature within the shock front can be sufficient to vaporize and inflame oil deposit in a pipe. The resulting combustion in turn serves to propogate the shock wave, which at higher speeds will attain higher temperatures and cause detonations within the pipe. Loison calculated a shock wave temperature of 870°F in a wave front traveling at 3300 ft/sec. (R. S. Ridgway (See next reference) reported a pipe line explosion in which some 32 miles of 10 inch "empty" oil line was ripped apart in ruptures at various intervals as explosions were propogated.)

From these experiments, Loison concluded the mechanism of explosions observed to be as follows:

A fraction of the lubricating oil is entrained by the delivery air in the form of fine droplets and these are progressively deposited on the walls of the receivers and piping network, impregnating the rust therein. This deposit decreases with distance from the compressors.

The air leaves the compressors at a relatively high temperature varying with the state of the installation and the delivery pressure. If the temperature of the air is increased accidentally and the supply of air is sufficiently low, the oxidation is accelerated and the temperature of the deposit increases. ---- If the variations in the air supply are such that at a given moment the concentration of combustible vapors attains the limit of inflammation, the vapors inflame and cause an explosion. These conditions are likely to arise when, with the oxidation reaction more or less accelerated, the air supply is suddenly cut off.

If the inflammable gaseous mixture is able to form in a section of pipe of sufficient length, the deflagration may initiate another type of explosion, fed directly by the oil deposit and capable of propogating at a high speed. ---

Although Loison's report was not directed towards remedies for the problem he was investigating, he concluded that prevention of explosions might be effected by:

1) Prevention of oil deposits in the compressed air lines.

2) Temperature control of the compressed air at its entrance to such lines through:

   a) Coolers.

   b) Thermostat control with automatic compressor cut off.

5. Reference:

"Eliminating Explosions in Air Starting Lines" - R. S. Ridgway (Standard Oil of California).

Ridgway reports that "ever since the practice of starting large internal combustion engines began by rolling them with compressed air admitted directly to the power cylinders, industry has had to face problems caused by explosions in the compressed air lines." Such explosions are not frequent but yet not uncommon. In a 1957 survey of the NGAA, 53 companies were questioned. Twenty had experienced one or more starting air line explosions. The common factor in all the mechanisms of explosions appears to be the lubricating oil. Use of more fire retardant oils was stressed.

6. Reference:

"The Carbon-Oxygen Complex as a Possible Initiator of Explosions and Formation of Carbon Monoxide in Compressed Air Systems" - H. W. Busch, L. B. Berger and H. H. Schrenk - U. S. Bureau of Mines Report RI 4465, June 1949.

This paper reports the existence of a carbon-oxygen complex on carbon deposits from air compressors. The formation of such a complex is an exothermic reaction. The existence of this complex on air compressor carbon was reported significant since its formation may act as a source of ignition at rather low temperatures. Experimental results showed that carbon deposits from compressed air systems produced definite evidence of exothermic reaction when heated to 250°C in air. One sample indicated reactions may start at temperatures as low as 150°C.

Regarding remedies for the explosion hazard, the author suggested:

1) The selection or development of lubricants that would minimize or inhibit the action of the carbon-oxygen complex.

2) Control of the operating temperature of air compressors.

3) The use of automatic, temperature-actuated shut off mechanisms reflecting excessive temperatures in discharge lines of air compressors.

7. Reference:

"Report of Air Flask Explosion in Land Based Prototype of the U. S. S. Triton at West Milton, N. Y. on October 30, 1959". Report dated November 6, 1959.

This report summarizes the findings of a special committee set up to investigate the incident. The committee reported that the design of the hydraulic accumulator was such that oil accumulated in the high pressure air flasks, thereby creating a potentially explosive mixture. The means whereby the mixture was ignited was not definitely established but the following possible mechanisms were listed:

a) Lifting of an air relief valve could have started a shock wave in the air system of sufficient intensity to ignite an air-oil mixture in the flasks.

b) Structural failure of the air flasks could have released an explosive mixture of air and oil. This mixture could have been ignited by hot metallic particles resulting from the bursting of the flask.

c) Spontaneous combustion resulting from decomposition or other chemical reaction of the oil in contact with the high pressure air in the flask.

d) The possibility exists that the man who was in the compartment at the time of the explosion was replacing a gauge on the high pressure air part of the system and, in the process, inadvertantly disturbed the system in some manner which initiated the explosion. Ignition of oil-air mixtures can be caused by compression or shock waves caused by rapid opening of a valve in a high pressure air system where oil is present.

8. Reference:

"Safety in the Compressor Plant" by C. W. Gibbs (Ingersoll-Rand) Compressed Air Magazine, Vol. 42, 1937, p. 5445-5449.

The author discusses safety aspects of both layout of a compressor installation and operation. Points made include the following:

1) Intake air should be cool and filtered.

2) An after cooler is recommended to condense both water vapor and excess oil. It should be protected with a safety valve and have a pressure gauge.

3) Valves and fittings should be carefully selected for the intended service.

4) Distance between compressor, after cooler and receiver should be as short as possible. No valves should be placed between receiver and compressor.

5) After coolers and receivers should have effective drains.

6) No valves should be installed between pressure regulators and the vessel in which pressure is to be maintained.

7) Cooling water to coolers should be clean, the source of supply reliable and a visual arrangement for checking of flow provided.

8) Oil lubrication should be minimized. Oil lying in valve pockets or cylinder discharge passages should be avoided. Quality of oil used should be checked.

9) Leaky discharge valves should be avoided. Frequent inspection of discharge valves should be made.

9. Reference:

"Safe Practices for Air Compressor Operation" by D. Attaway (Safety Engr., Arkansas Fuel Oil Co.). Petroleum Refiner, Vol. 25, No. 6, June 1946, p. 282-4.

The following safe practices for air compressor operation were included in this article:

1) Compressor lubrication

The proper amount of oil to be used in the air cylinder depends upon viscosity of the oil. Little oil is required to maintain operation. Lubrication of the air cylinder, when incorrectly handled, is believed to be one of the largest causes of explosions. At a pressure as low as 100 pounds, the temperature of an air cylinder often reaches 480°F which is sufficient to vaporize certain grades of lubricating oil. When this vapor is mixed with air an explosive mixture is formed that may be readily ignited by a glowing bit of carbon or by temperature alone. A good rule suggested for oil lubrication was 1 to 4 drops per minute for small compressors, six drops per minute for medium sizes and 10-12 drops per minute for large compressors.

2) Decomposition of oil and Carbon Deposits

Only high grade mineral oil should be used that contain no animal or vegetable oil. Even the best oil decomposes to some extent and leaves a carbon deposit that is carried into the receiver and piping. This carbon is flammable and soon becomes oil-soaked. It is under air pressure and exposed to great heat, so it may glow or burn thus igniting any explosive mixture of oil vapor.

A carbon deposit may be distributed to form a dust which may explode when mixed with air and ignited.

Faulty compressor discharge valves cause a sharp increase in air temperature. Friction alone may ignite carbon. Compressor valves should be cleaned at least once each month or oftener if service is continuous.

3) Clean Cool Air at Intake

Explosions may occur by ignition of flammable vapors drawn in at the intake. The intake should be located where air is clean and cool. An air filter should also be installed.

The air intake pipe should be 8-10 feet above ground level, or above the roof, yet short and straight as possible to avoid pockets, turns or traps where substances may accumulate. If the intake has such pockets, drains should be installed and checked daily. Moisture has no effect on fire or explosions but does cause a corrosion effect.

Every means should be used to keep the cylinder temperature down. This will decrease vaporization and decomposition of lubricating oils. This is accomplished by keeping ample cooling water circulating, drawing only clean cool air into the cylinder and operating the compressor at a speed no greater than rated.

4) Cooling Water

Deposits of scale form on the cylinder water jacket reducing the cooling effect. It is advisable to clean these pockets at least once a year.

5) **Fusible Plugs**

Each air compressor should have a fusible plug in the discharge piping to relieve pressure when temperature exceeds a certain limit --- perhaps fixed at 350°F to 500°F, depending upon compressor size.

6) Discharge Piping

Discharge piping should be at least the diameter of the opening in the air cylinder and should be carried full size to the receiver. Bends, turns, and loops must be avoided. ----

7) Air Receivers

The receiver should be as close as possible to the compressor and in a cool place. Each receiver should have a pressure gauge, safety valve and blow-off cock.

A shut off valve should never be placed between the compressor and the receiver unless a safety valve is placed on the compressor side of the valve. Air outlet from the receiver should be at the top.

All piping, fittings and equipment must withstand a test pressure of 1-1/2 times normal operating pressure. Air receivers should be constructed to ASME Code.

8) Air Starting Piping

Air starting lines should have two check valves located at least 10 pipe diameters apart. In case of engine backfire, glowing carbon may be blown past a single check and ignite flammable vapors present in the air receivers and piping.

10. Reference:

"Minimizing Explosions in Compressed Air Systems" by T. D. Brown (Acting Area Superintendant, Shell Pipe Line Corporation, Colorado City, Texas), Oil Weekly, Vol. 109, No. 11, May 17, 1943, p. 12-14.

The author discusses the hazards involved in the operation of compressed air systems, particularly with respect to the accumulations and ignition of combustible materials. As with previous articles, the author states that fire or explosions in compressed air systems require two conditions: 1) A combustible mixture and 2) a temperature high enough to ignite the mixture. The article includes the following pertinent points:

1) Combustibles may enter compressed air systems through the air intake, from the lubricating oil, or by leakage into the system. The compressor cylinder lubricating oil is usually the chief source.

2) Cylinder lubricating oil may be vaporized depending upon the temperature of the cylinder. Vaporization usually commences at temperatures well below flash point and increases as temperature increases.

3) Vapors are also created by chemical breakdown and oxidation. Small amounts of sulphur often present in lubricating oils, may create sulphur gases or compounds that are inflammable and corrosive.

4) Some oils break down to form carbonaceous deposits on the piston. Lubricating oil should have a high flash point, a low carbon content and be as free of sulphur as possible. Only a high grade mineral oil meets these requirements.

5) The practice of cleaning compressor parts with kerosene or gasoline may substantially reduce flash points of oils used and contribute combustible materials.

6) Ignition temperatures are possible through spontaneous combustion, faulty operating conditions and faulty components.

7) The importance of cooling is emphasized by stating that the adiabatic discharge temperature for air at 14.7 psia and 60°F when compressed single stage to 100 psig is 485°F, at 150 psig is 589°F and 250 psig, 749°F. Corresponding temperatures for two stage compression are 243°, 270° and 331°F.

8) With respect to minimizing explosions the following can be summarized:

   a) Use oil of high quality - high flash point, low carbon content, free of sulphur.

   b) Take care to prevent contamination of lubricating oil by low-flash point liquids.

   c) Probably the safest air compressors are those that do not require oil for lubrication.

   d) Air intakes should be located out of doors where a supply of clean, cool air is readily available and they should be equipped with filters.

   e) Control of discharge temperature through compression in stages, cooling of air between stages and effective cooling of the compressor.

   f) Avoidance of leaky discharge valves.

   g) Installation of thermometers and pressure gauges on air intake and on the discharge of each compression stage. Thermometers should be installed on inter-coolers and after coolers and the receivers should be equipped with pressure gauge and thermometer.

h) Visable means of checking the amount of oil to the compressor cylinders and the circulations of the cooling water should be provided.

i) Fusible plugs in the discharge lines afford some protection by warning that an excessive temperature has existed; however they do not protect against instant or localized ignition temperatures.

11. Reference:

"Hydraulic Accumulators" by E. M. Greer (Chief Engineer, Greer Hydraulics) Machine Design, Vol. 25, No. 11, 12, November 1953, p. 140-1; December, p. 248-9; Vol. 26, No. 1, January 1954, p. 132-5.

This series of articles briefly describes the various types of accumulator designs including gravity, spring-loaded, pneumatic, inflexible separator and flexible separator types. In regard to the floating piston design, the observation is made that this type has a number of disadvantages. These include:

1) Piston friction has a detrimental effect in pressure-regulator systems.

2) After a period of time, oil leakage occurs, requiring that the unit be drained and recharged at intervals.

3) Packings wear and require frequent replacement since normal leakage cannot be tolerated.

4) When used as a surge chamber or shock absorber has proved unsatisfacotry since inertia and acceleration factors of the piston itself intensify pressure peaks.

12. Reference:

"Fire Resistant Hydraulic Fluids" - Applied Hydraulics, Vol. 10 April 1957, page 78-82; June 1957, pages 124-128; August 1957, pages 114-121; September 1957, pages 168-173; October 1957, pages 160-162; November 1957, pages 116-118.

This series of articles discusses and compares characteristics of various fire resistant fluids including pure synthetics and mixtures of water and water soluable synthetics, i.e. "Snuffer" type fluids, whereby fire resistance results through release of a protective steam blanket in the presence of high temperature. This latter type includes an emulsion which consists of petroleum oils mixed with water and emulsifying agents.

Aqueous base fluids depend on water content for fire resistance. This requires a temperature limit (generally in order of 150°F) on its application and the need for periodic makeup. Viscosity changes as a function of water content. Other special considerations in the use of aqueous fluids include:

1) Solvents effects on paints - softening and lifting of many of the conventional types of paints and coatings will result.

2) Because of the high water content, the high vapor pressure at elevated temperature will result in loss of water and some of the volatile inhibitors.

3) Zinc and cadmium metals are frequently dissolved by aqueous fluids.

4) Grease is not soluable in these fluids. Excess lubrication may result in filter clogging.

Non-aqueous fluids of the phosphate ester type will harm packings compatible with petroleum oils. Static seals will swell in time. In dynamic seals such swelling will cause them to tighten and rub on the moving parts. Where systems are being changed over to this type of fire resistant fluid, change of seals is recommended. (It is understood that butyl type rubber is resistant but a saftening effect occurs on "Neoprene" or Buna N rubber.)