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High-Pressure Equipment: Hazards, Operation, and Safety, with Emphasis on the Haskel Air Intensifier Pressure System

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Contents

Abstract

The words "high pressure" can hold various meanings, and today, high-pressure technology is used in a wide variety of industries. Because energy is stored, pressure systems can be hazardous. Under certain circumstances, this energy can suddenly and unexpectedly be released, causing injury to personnel and/or damage to a facility. Therefore, when planning, designing, and determining operational procedures for pressure system use, the identification of hazards must be given the highest priority.

Although the pressure vessel represents the single largest source of potential energy within a process system and its failure could be extremely catastrophic, malfunctions in system components such as piping, valves, compressors, and pumps could also lead to equally catastrophic failures. Therefore, operator training must be thorough; it must not be cut short. Operators must develop an attitude and an awareness that is based on respect of the pressure systems, and they must be aware that equipment subject to pressure must be routinely inspected to prevent unsafe operating conditions.

History

High-pressure technology began shortly before 1249 with the discovery of gunpowder by Roger Bacon. It was only after continuous attempts to harness steam power that leading advancements in pressure technology began to occur. In 1663 a patent was awarded for the first working steam engine, and in 1769 the use of pressurized steam became feasible with the development of the steam locomotive by James Watt. A number of applications soon followed, especially in the area of power for industrial machinery. Although these pressures were relatively low (1500 psi), frequent failures of boilers led to the adoption of safety regulations and codes.

By the late 1800's, Amagat was publishing work involving pressures up to 45,000 psi, and the use of chemical reactors on an industrial scale was becoming quite common. Following the recognition that high pressures meant that gases could be liquified, the first synthetic ammonia plant was built in 1913. By 1939, the first production plant for polyethylene was started, utilizing pressures of 22,500 psi. The military recognized the importance of polyethylene for submarine cables, radar, and other military applications, and the technique of autofrettage for gun barrels demanded pressures up to 150,000 psi.

Between 1906 and 1961, Bridgman published many papers, and one of his developments led to the synthesis of diamond and its commercial exploitation that required pressures in the region of 750,000 psi. Today, high-pressure technology is used in a number of industries, and the words "high pressure" mean different things to different people.

High-Pressure Systems

Although the term "high pressure" has several meanings, it is usually considered to be any pressure above 3,000 psi.

A high-pressure system can be defined as an integrated array of pressure-containing components, typically consisting of pressure vessels, piping, valves, pumps, gauges, etc. The Mound system, a Haskel air-driven hydraulic intensifier system (Model 54705) presently being used to pressurize mild detonating fuses (MDFs), is capable of producing pressures up to 150,000 psi, although Mound's primary interest falls within the pressure range of 40,000 to 100,000 psi.

Pressure System Hazards

Pressure systems are inherently hazardous because they involve energy that is stored. Hazards can arise from a number of sources, some of which may be totally unexpected. Some of the most common hazards include unexpectedly high pressure, failure of the design or the end product to meet acceptable criteria, built-in defects, human error, lack of good established procedures, and lack of fail-safe mechanisms. Identification of hazards must be given the highest priority to ensure consistently safe operation. Once a hazard has been identified, steps can be taken to guard against it.

Protective Shields

A protective shield is a barrier between a pressurized component and personnel. It is designed to protect against the hazardous effects of rupture or leakage. Protection against a potential hazard is primarily a matter of judgment. Therefore, in designing structures to guard against hazards, the first step is to evaluate both the operation and the system. Each piece of hardware must be evaluated to determine its potential hazard level. The design must also be evaluated based on the total available energy contained within the system.

The energy within a system is both chemical and physical. This energy can be defined as the sudden release of high-pressure media, followed by the generation of a shock wave, as in an explosion. The released energy is often converted into an equivalent weight of TNT (1.51×10^6 ft-lb = 1 lb TNT), especially when a containment chamber is not used. Based on this information, available data that recommend distances from the energy release to reduce the shock wave pressure to a safe level for both personnel and various structure types can be obtained. The energy release in most cases is the result of overstressing a pressure vessel because of an uncontrolled chemical reaction, a mechanical reaction, or a combination of the two.

Mechanical failures are attributed to fatigue, stress corrosion cracking, or other corrosive failure mechanisms. As a component fails, energy is dissipated in a number of ways. First, there is some absorption by the failed component (wall, closure, etc.). Next, the gas or fluid reexpands in the form of a shock wave. Finally, energy is imparted to fragments, turning them into high-velocity missiles. Consequently, it is important to orient equipment so that potential missiles will be propelled in the direction in which they will cause the least harm. The degree of the potential hazard depends heavily on the location of the pressure operation, as well as on the length of time personnel are present. Therefore, the next step is to determine the type of protective shielding needed.

Remote Operation

A pressure operation can be justified in a manned area only when it has been demonstrated to be safe. If safety cannot be demonstrated, unmanned (remote) operation is mandatory. In fact, the best possible locations are those that are remote from all personnel.

Secondary Containers

Although remote operation provides the best protection, the most effective protective shield is probably a secondary container that has a design similar to a large steel pressure vessel. Used properly, it is capable of containing the explosive force and preventing any external damage (Figure 1).

Barricades/Cells

The barricade or cell is considered by some as the least effective type of shield. This is because, functionally,

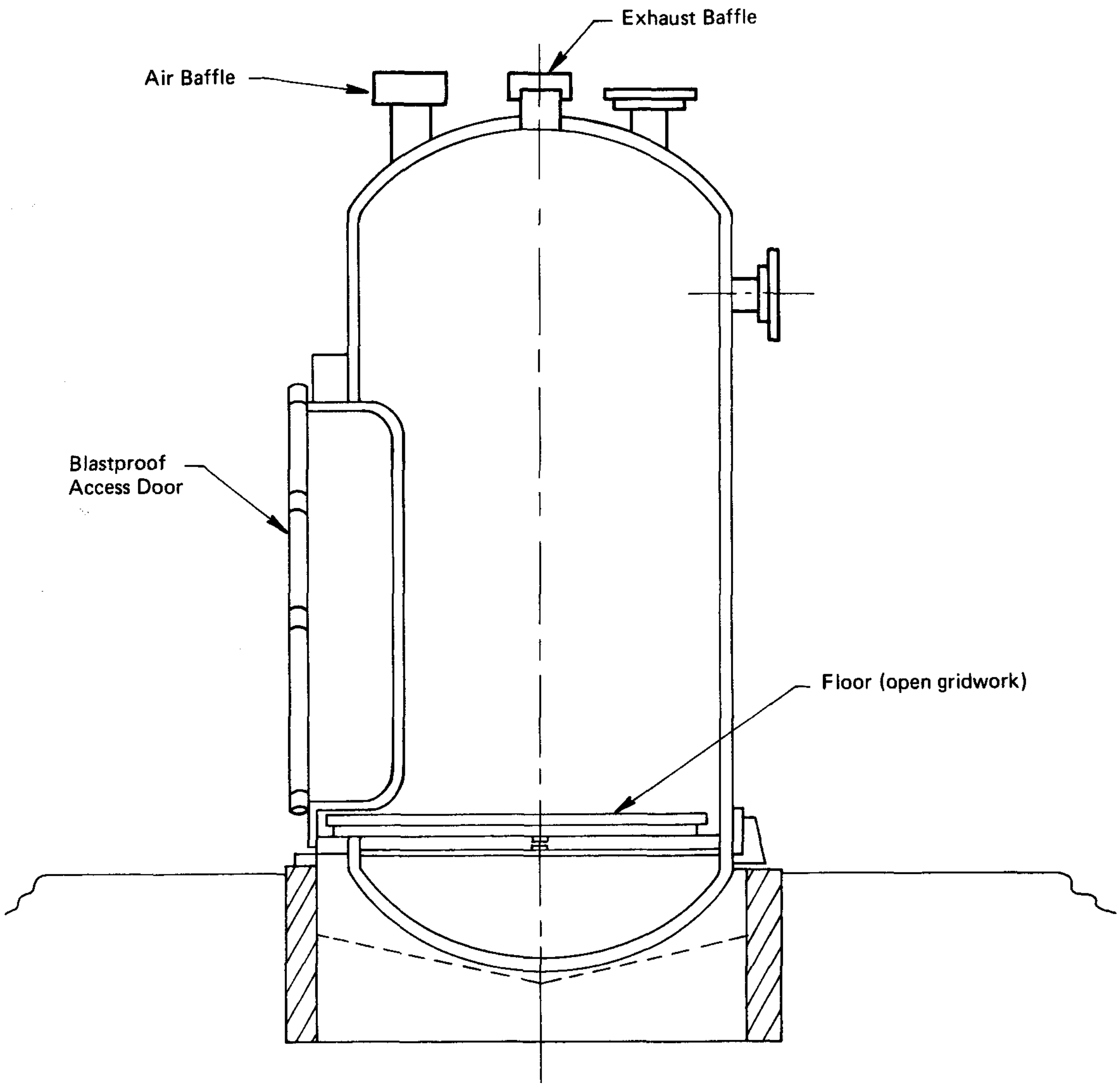

FIGURE 1 - Secondary container.

it is designed primarily to provide a barrier against penetration only. Penetration or missile resistance is difficult to quantify since quantification requires the prediction of the possible size, shape, weight, altitude, trajectory, and velocity of a missile. The traditional barricade design consists of a reinforced concrete structure with one frangible wall and, in some cases, the roof acts as a frangible to permit venting (Figure 2).

After a protective shield is fabricated and put into place, all operators should become acquainted with its safety features and methods for safe operation.

Operation of Model 54705

The Mound system, located in a cell in DS-Building, is housed in a stainless steel cabinet made of 1/4-in. thick cold-rolled steel (CRS)-plated front panels and 2-in. thick hot-rolled steel (HRS)-plated blast panels (Figure 3). Because of the lack of sufficient air pressure from existing air lines, an air amplifier provides a means of boosting the available plant air from 80 psi to 100 psi. The regulator on the tank output is used to control the output pressure into the system. The inlet air is controlled with the use of a speed control valve (34 in Figure 4) and monitored by an air regulator and gauge (32 and 31 in Figure 4, respectively). The compressed air is then fed into the air drive section of the drive pump, which is allowed to cycle at its maximum speed to produce maximum flow. Compressed air used as a power drive reduces the risk of excess heat, flame, spark, and shock.

The drive pump, acting on the automatic reciprocating differential area piston

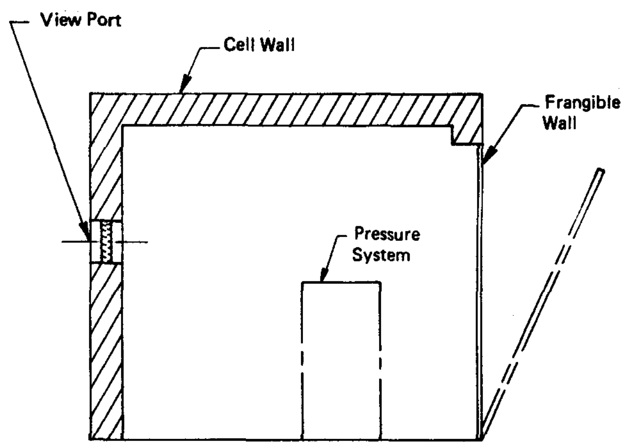

FIGURE 2 - Barricade/cell.

principle, uses a large area drive piston to convert the compressed air into hydraulic power. The hydraulic fluid then enters the low-pressure port of the intensifier. The hydraulically driven intensifier, also based on the differential area piston principle, is used to raise large volumes to a high pressure in a short time, as well as to reach these high pressures with few pulsations. The large, low-pressure (11,000 psi) hydraulic cylinder provides the force necessary to drive the smaller, high-pressure (150,000 psi) liquid end plunger.

Isopar H, the high-pressure liquid or pressurizing medium, is a carefully fractionated isoparaffinic hydrocarbon of exceptional purity manufactured by the Exxon Company. The Isopar is pumped into either of two pressure vessels located in the hinged access portion of the pressure system cabinet.

A pressure vessel is defined as a container capable of maintaining a fluid at a pressure other than atmospheric pressure when all inlets and outlets are closed. Two pressure vessels are shown

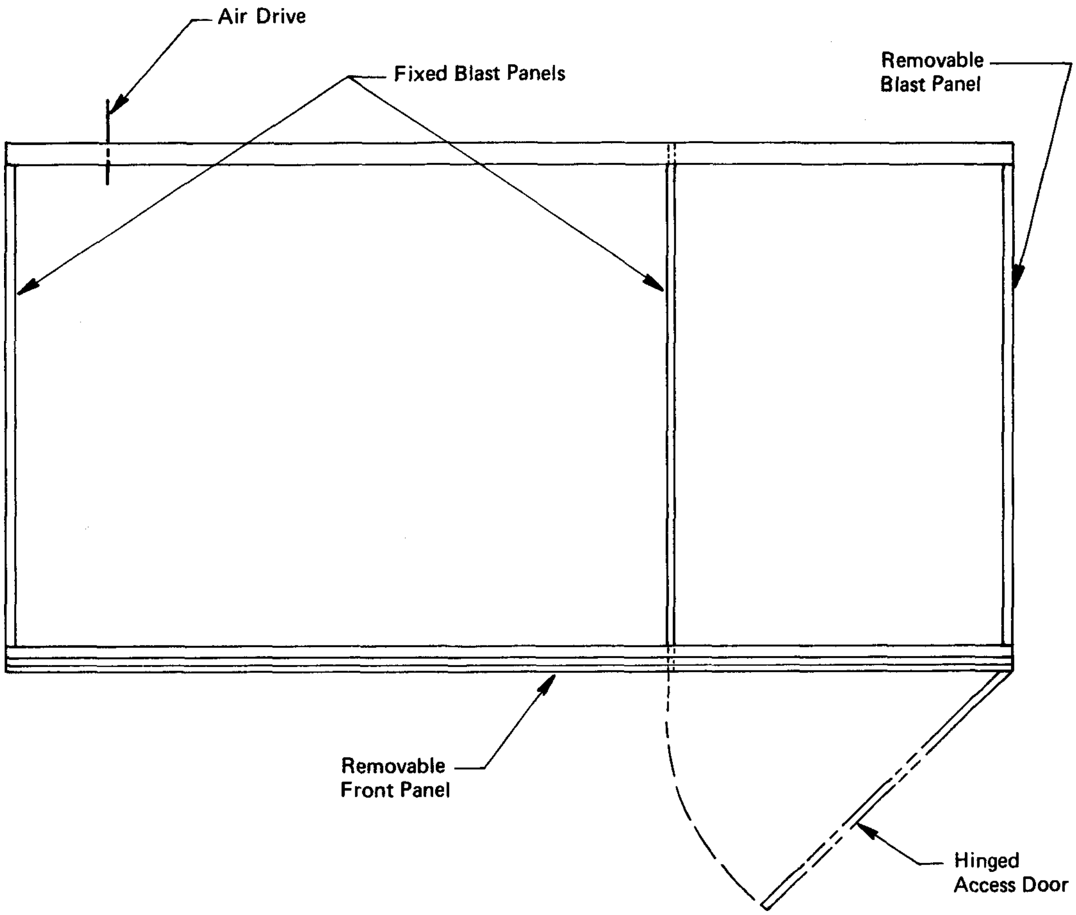

FIGURE 3 - Top view of Mound pressure system cabinet.

in Figure 5. The first vessel, used mainly to pressurize straight-length pieces of MDF, is rated for 100,000 psi and has an i.d. of 1 in., an o.d. of 5-1/2 in., and an inside depth of 26 in. The second, used to pressurize MDF helices, is also rated for 100,000 psi and has a 2-in. i.d., a 12-in. o.d., and an inside depth of 6 in. A diagram of the inside of a typical pressure vessel is shown in Figure 6. Both vessels in Figure 5 are one-piece closure systems made from high-alloy steel, heat-treated for dependable high-pressure service, and blackened to prevent rusting.

Because the efficiency of a pressure vessel is directly related to the effectiveness of its closure, the ideal closure should not only satisfy both the design temperature and pressure requirements, but should also permit relatively easy access to the interior of the vessel, be easy to maintain, and have a low maintenance cost. It is almost impossible for any single vessel to meet all of these conditions; therefore, a compromise must be made. Both closures on the Mound vessels incorporate a curved buttress thread and can be quickly and easily removed by disengaging the cover

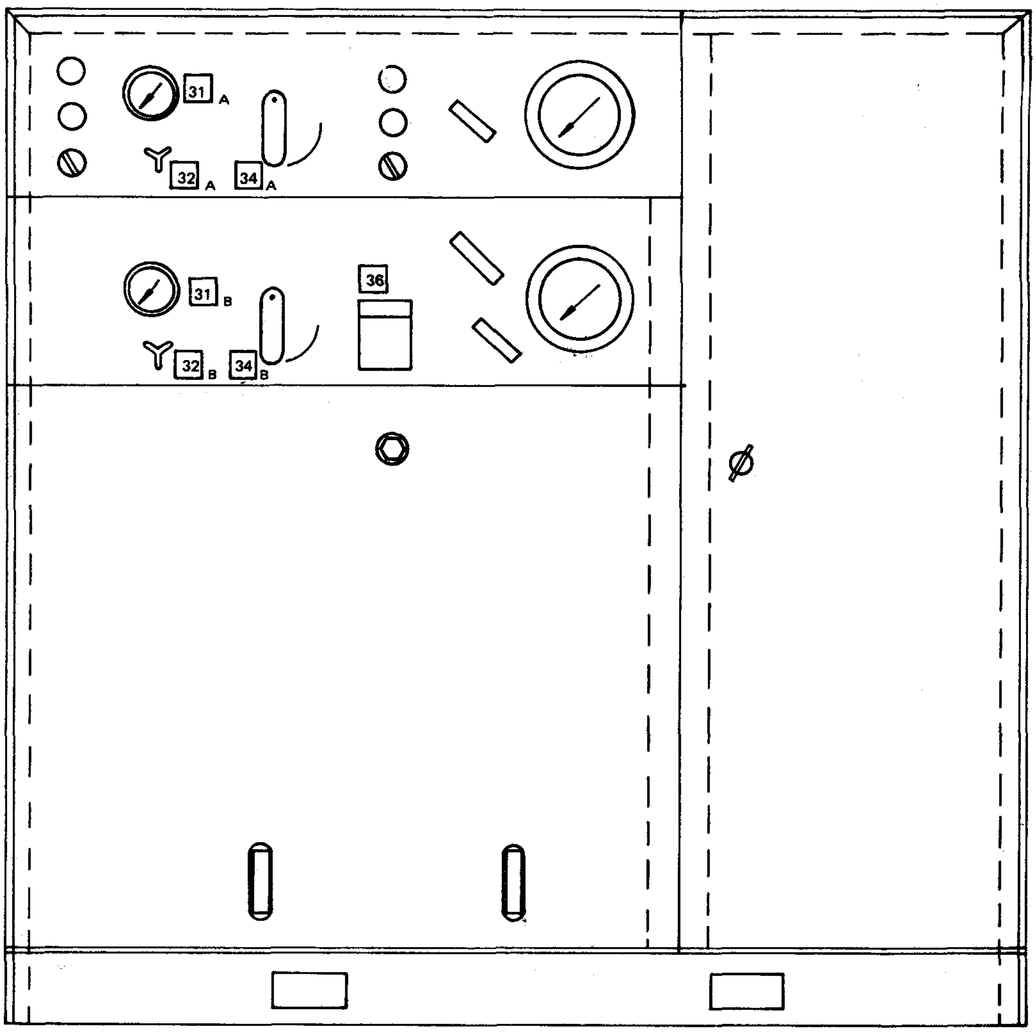

FIGURE 4 - Front panel of Mound pressure system cabinet.

nut with approximately nine revolutions. This self-sealing O-ring closure (Figure 7) is backed up by a metal wedge type back-up ring that actually moves and stretches under pressure to ensure that the O-ring is perfectly confined and that there are no clearances in which the O-ring could extrude. Because of the Buna-N seal, the maximum temperature of either vessel must not exceed 250°F. A vent hole is also incorporated to prevent pressure buildup behind the closure in the event that a worn or damaged seal leaks.

Instrumentation and Pressure-Relieving Devices

To provide a safe operating environment, instrumentation and pressure-relieving devices must constantly be maintained. Several pressure-relief devices have been installed in the Mound system to ensure that pressure levels stay within predetermined safe limits in spite of possible equipment malfunctions. Instrumentation in pressure ranges approaching 50,000 psi is highly specified. Therefore, the digital pressure indicating system, which is extremely sensitive

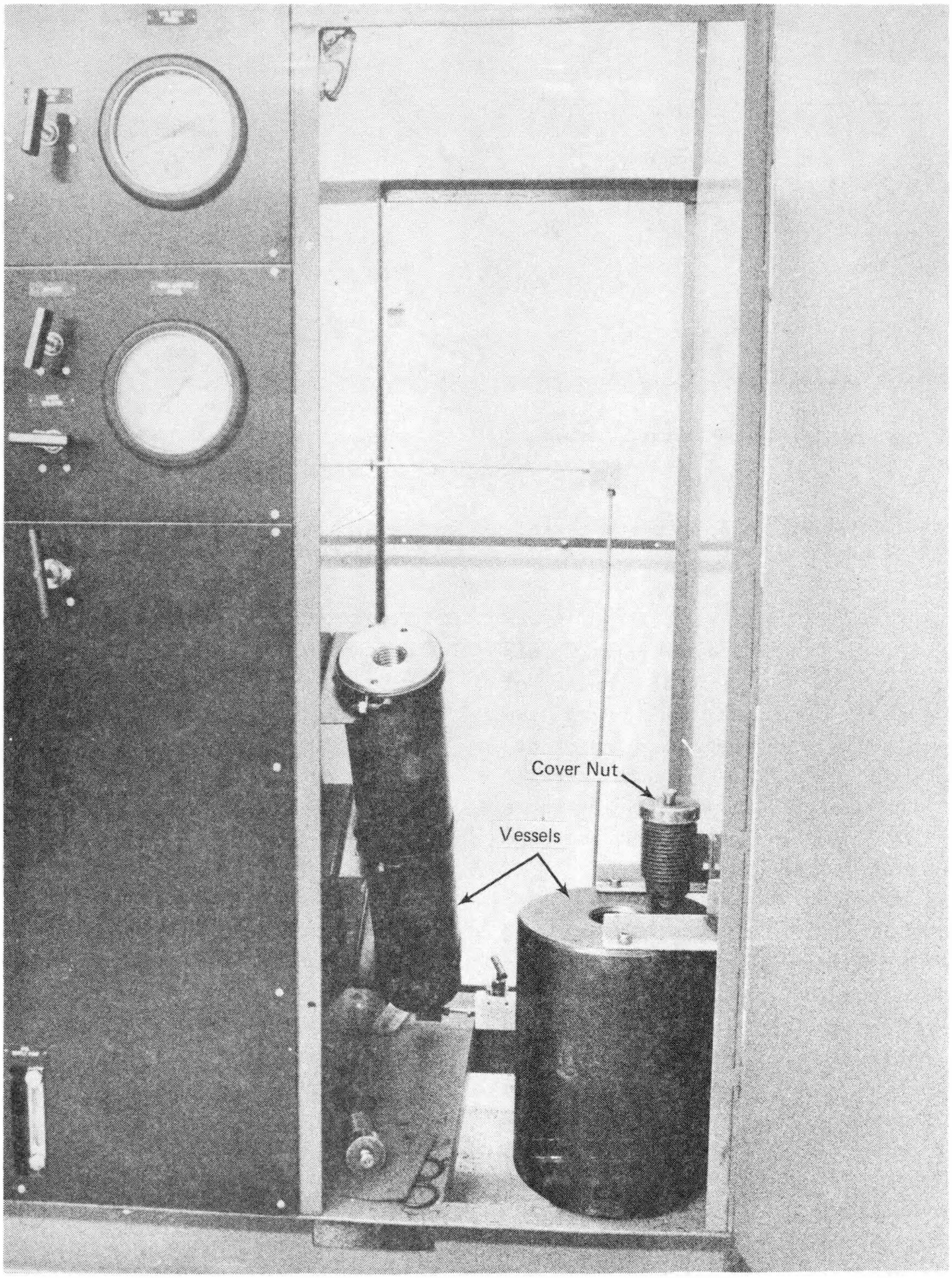

FIGURE 5 - Pressure vessel on left is used to pressurize straight-length pieces of MDF; vessel on right is used to pressurize MDF helices.

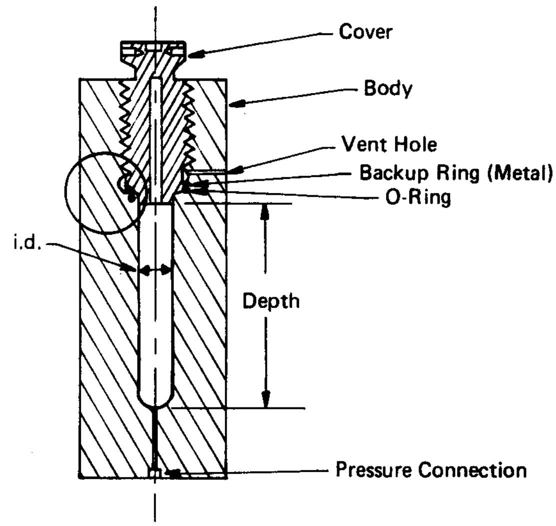

FIGURE 6 - Inside of a pressure vessel. (Circled area is enlarged in Figure 7.)

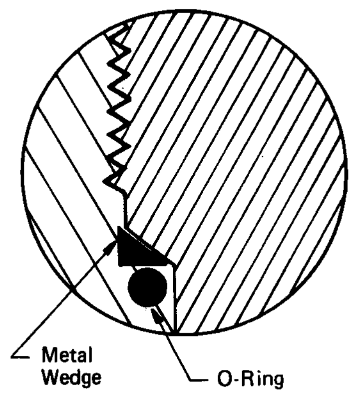

FIGURE 7 - Self-sealing O-ring closure and back-up ring.

equipment, should be shut off at pressures greater than 100,000 psi. This system provides an accurate means of measuring the high pressure output and consists of a single channel indicator, an interconnecting cable, and a transducer. Direct reading of the pressure output is obtained via a light-emitting diode (LED) display.

Operator Training

Operator training must be thorough and cannot be cut short since it affects not only safety but the reliability of the equipment. During training, the operators should develop an attitude and an awareness that is based on respect of the system and not on fear. As part of training, the fact that knowledge of the equipment is mandatory for safe operation should be emphasized. Specific equipment categories to be considered include piping and tubing systems, high-pressure valves, pumps and compressors, and pressure vessels.

Piping and Tubing Systems

A general understanding of the piping connections and how these connections work is important. Operators should observe, during the normal course of operation, piping joints, fittings, and valves that have been less than reliable (i.e., they have previously leaked). To ensure safe operation, substandard materials should never be substituted, piping and tubing should be supported during high-pressure service, and, as always, cleanliness is essential.

High-Pressure Valves

Most difficulties discovered in valve operation relate to the method of installation. Again, it is extremelv important to take notice of leaks and to guard against corrosion and dirt. Cracks in high-pressure valves can result in severe personnel injury and equipment damage.

Pumps and Compressors

Dirt and/or other foreign materials are usually considered the main culprits when reciprocating equipment (pumps and compressors) is installed. Improper alignment of inlet and outlet piping can cause problems as well. The compressor or pump is subjected to the highest degree of cycling and has the greatest potential for fatigue failures. Failures resulting from fatigue are usually unobservable during a routine inspection and can only be prevented by the use of nondestructive methods to detect early fatigue cracks.

Pressure Vessels

The safe operation of pressure vessels and their maintenance should be a primary concern to personnel since pressure vessels represent the single largest source of potential energy within a process system. Safety and maintenance must begin at the time of order placement with the vendor, and responsibility for safe use of the pressure vessels rests mainly with the operator. Important documentation can be obtained from the vendor during the fabrication and testing phases of manufacture that provides a baseline from which future vessel inspections can be made. This information should contain a record of internal and external dimensions at key locations, as well as a description of nondestructive testing procedures. It is up to the operator to then decide the frequency and extent of an inspection program. An annual inspection is recommended for pressure vessels meeting one or more of the following criteria:

1. Pressure vessels designed for service above 30,000 psi.

2. Pressure vessels that normally handle a liquid medium and for which the product of the volume in cubic inches multiplied by the design pressure in psig exceeds 1,000,000.

3. Pressure vessels subjected to more than 5,000 cycles per year.

4. Pressure vessels that are used for corrosive media.

During the inspection, the vessel should be completely disassembled and cleaned externally and internally. A complete visual inspection should be made, and all internal surfaces should be inspected using a liquid penetrant. A complete ultrasonic and magnetic particle examination on magnetic steels should be performed. It is also good practice to replace seal rings or gaskets at this time. All results and procedures should be recorded.

Summary

Because of work with high-pressure equipment, Mound personnel are aware that there are a number of hazards that may arise, some of which can be totally unexpected. Identification of some of these hazards allows personnel to guard against them to ensure consistently safe operation. To reduce the potential hazard level, protective shields must be used. After these barriers are in place, operators should be acquainted with their safety features and methods for safe operation. Operator training should always be thorough, and operators should gain in-depth knowledge of the equipment since this knowledge can affect not only safety, but reliability as well. Because the term "high pressure" holds different meanings in various industries, research in this area must be continued as high-pressure applications continue to grow.

Additional Reading

Pressure Safety Advisory [illegible] Pressure Safety Practices Man[illegible] 0424, Sandia Laboratories, [illegible] NM and Livermore, CA (March 1[illegible]

Crum, Andrew S.D., "Hig[illegible] Technology," presented at [illegible] Pressure Technology Seminar, [illegible] for Professional Advancem[illegible] Brunswick, New Jersey, 12-14 [illegible]

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