# What's so sacred about 14.7 psi?

In prior years our research was restricted to whatever we could do at one atmosphere pressure—14.7 psi—or less. That's as silly as running all our chemistry at 20 °C (18 °C this past winter). We just lacked facilities for the safe operation of moderate- and high-pressure reactions. In addition, our need to extend many lab preps to developmental scale-up could not be realized. Commercially available barricades and pressure equipment just didn't seem suitable. Stock equipment, such as hydrogenators and small reactors, were useful when shielded, but most lacked provisions for safe remote manipulation. At the opposite extreme, a large, sophisticated installation incorporating several cubicles with remote operation of fixed or mobile autoclaves behind massive concrete walls and revetments, all in a specially designed building, exceeded our financial resources as well as our requirements. Between these extremes, there has long existed a need for a moderate-cost facility in which to do chemistry under pressure, to permit safe thermodynamic measurements, and to study kinetics of batch and continuous high-pressure pressure reactions. It was also important that the facility should be adaptable to process development, including scale up of promising laboratory reactions.

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Well, we solved the problem to our satisfaction and would like to describe the design, equipment, use, and advantages of our moderate-size pressure laboratory, which has been constructed and equipped at relatively low cost.

We tried to adopt the best safety features we saw in other pressure laboratories, as well as what we found in the literature (*1–9*). The size of our unit permitted construction within an existing building, thereby reducing costs.

The key characteristics we incorporated into the laboratory include:

- A compact-welded barricade with walls constructed of two 1-in. steel plates with 3-in. radii corners not requiring expensive supporting foundations.
- A blast-resistant viewing port of special design for ready maintenance.
- An OSHA-approved (*10*) purged-operator control panel incorporating safety and explosion-proof features that facilitate trouble shooting.
- An energy-conserving heating and exhaust system that prevents build up of bulk explosive atmospheres.
- A modified double-end compressor, which is practically maintenance free, for simultaneous compression of two gases. It serves in lieu of separate compressors.
- A fire extinguishing system interlocked with an automatic door closer and failsafe system (Halon 1301).
- Explosion-proof wiring in barricade and lab (National Electrical Code for a Class 1, Group D, Division II).
- Steel guide plates and blow-out vents to relieve pressure caused by an explosion in the cubicle.
- Reactors in place include a 1 liter, 316SS autoclave, a 1 liter Hastelloy C reactor, a 2 gal 304SS reactor of special construction, and a 30 in. (0.5 liter) 316SS reactor tube.

### General laboratory layout

The laboratory (Figure 1), which is housed in our Hazardous Operations Building, is a brick and reinforced concrete structure with a pan-type concrete roof. Approximately a third of the wall area is paneled glass that is scored for facile blow-out.

### The barricade (cubicle)

Reinforced concrete has generally been used for construction of lab barricades (*1–9*). However, concrete has several disadvantages in an intermediate-size installation such as ours: higher cost than steel, requirement of a reinforced foundation for support because of limited floor loading in existing building, and a tendency of the outside of the barricade wall to spall, shatter, and spray concrete missiles induced by transmission of a shockwave through the wall. A low bid showed the construction cost of a concrete barricade to be about two-and-one-half times the cost of the steel barricade (including delivery and rigging).

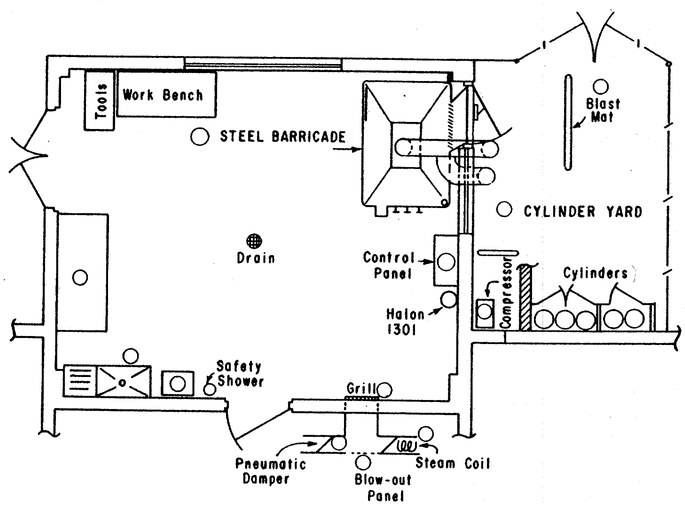


**Figure 1.** The high pressure lab

**The room, barricade, and hood are equipped with Class 1, Group A, Division II, explosion-proof fluorescent fixtures. The electrically conductive floor of the laboratory has a drain centered outside the barricade that is completely isolated from all other drains in the building**

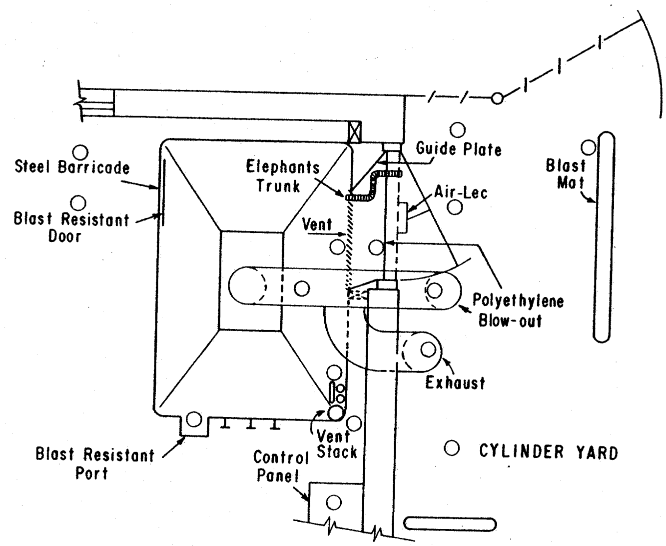


**Figure 2.** Detail of steel barricade

On the basis of these differences, steel (A-36) was used for the construction of the barricade (5 tons, 5 ft × 6 ft × 12 ft) (Figures 2 and 3). The walls were welded from two 1 in.-thick steel plates whose corners were bent on a 3 in. radius for extra strength. These plates were fillet-welded where they meet to form the entrance and vent (E, Figure 2). A 1 in. steel plate floor was welded to the walls of the barricade. The ceiling of the cubicle has 3 in. × 3 in. × 0.375 in. welded, angle iron, cross members from which a trolley and chain hoist are fastened. These members, which add strength to the barricade, support a 0.75 in. steel cable blast mat (1000 lb.). The mat will stop a missile but allows passage of gas. A 0.5 in.-thick steel roof is welded to the inside of the barricade above the blast mat. The barricade is exhausted through a 16 in. diameter elbow in its roof.

Entrance to the steel barricade is provided through a 1 in.-thick sliding door. A wharf trolley supporting this door is welded to the *inside* of the barricade so that the door cannot be blown open. Opposite this entrance is a 2.5 ft × 5 ft welded steel vent (grating), which allows passage of gas, but will retain some missiles. This vent is located 5 in. from the door frame to prevent transmission of barricade vibrations (Figure 4). The door opening has been covered with a 4-mil polyethylene blow-out panel that also provides weatherproofing. The building door, which must be open to operate the barricade, is interlocked with an automatic door opener and a failsafe circuit.

The location of the barricade relative to the walls of the laboratory and the position of the steel guide plates (0.25 in. thick) with respect to the door frame are important to the stability of the building in the event of an explosion. These plates, tack-welded to the bottom of the vent, extend downward to the threshold plate terminating just before the polyethylene blow-out panel. Two additional guide plates are tack-welded to the sides of the vent and extend to the sides of the door frame immediately in front of the polyethylene blow-out panel (Figure 4). These guide plates direct some shockwaves, missiles, and expanding gases from an explosion out of the barricade toward the blast mat in the cylinder yard (Figures 1 and 2). Tack welding the guide plates allows them to bend and helps prevent movement of the barricade from damaging the building. The air space between the barricade and laboratory walls is open at the top of the guide plates (see Figure 4) to allow for barricade make-up air.

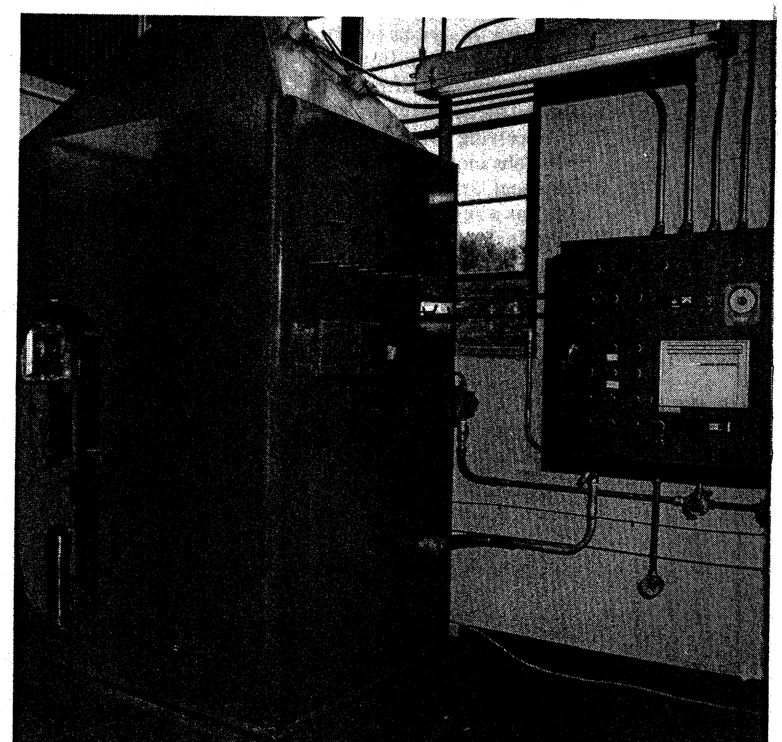

**Figure 3.** Barricade and control panel

### Fire extinguisher

Upon activation of the fire-extinguishing system, Halon 1301 floods the barricade and would flow into the cylinder yard if the polyethylene panel burned or ruptured. Halon could also flow from the vent between the outside of the cubicle and the adjacent concrete walls into the laboratory area. To prevent loss of Halon to the cylinder yard, the door is equipped with an Air-Lec pneumatically operated door closer (Figures 2 and 4). This equipment, which can also be operated manually, will, upon initial discharge of Halon, automatically close the building door within 3 seconds. A failsafe circuit simultaneously shuts the exhaust fan and sounds an alarm. The guide plates form an excellent barrier against loss of fire-extinguishing agent to the laboratory.

### Viewing port

The blast-resistant viewing port (Figures 2 and 3) consists of a 0.5 in. steel box in the operator's side and a 0.25 in. steel frame on the inside of the barricade. Welded construction was used throughout since bolts may fail in tension from an explosion. The port windows are two 4 in.-thick panes of Plexiglas 3 in. apart. Both windows are larger than the steel box opening and cannot be blown out.

The size and geometry of the reactor system containing fixed quantities of specific chemicals must be considered in formulating a safe barricade design (*9*). The port may be readily dismantled for maintenance.

### Floor drain

The calculated risk of excluding a floor drain from the barricade was taken to avoid the danger of seepage of flammable or noxious vapors into the barricade past a drain trap, especially with negative air pressure within. The barricade design allowed the alternative of safely containing spilled solvents inside the unit, since the rim of the barricade across the entrance and vent extends approximately 6 in. above the barricade floor. Spills may be vacuumed and discarded into a safety can or emptied into a sump.

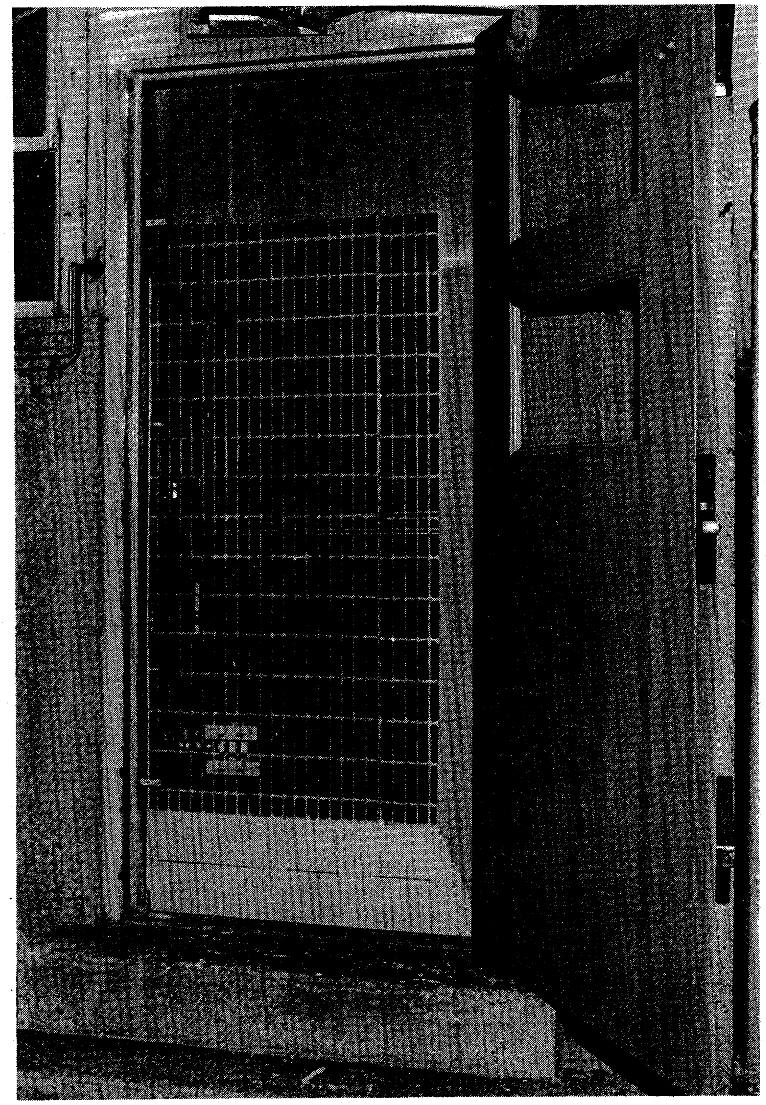

**Figure 4.** Barricade vent from the cylinder yard with polyethylene panel removed, showing the guide plates and the Air-Lec door closer

### Ventilation and heating

The laboratory's concrete roof, within which are embedded hot water pipes, functions as a radiant panel. Special reinforcement in the roof allows for heavy snow loading (design load: 2 psig). Make-up air, for heating and exhausting, is drawn from an attic room in which fresh, clean outside air, passed over steam heated coils (Figure 1) enters the laboratory through a grill in a restricted flow when the cubicle exhaust is operated. A considerable amount of energy is saved by this heating set-up since an automatic steam valve opens fully only in response to demand. The laboratory air is changed once every three minutes through the barricade exhaust, while air in the barricade is changed approximately ten times per minute (*5*). *This design helps prevent accumulation of toxic or explosive vapors within the barricade.* Pneumatically operated dampers in addition to the blow-out panel afford safe ventilation. Air from adjacent laboratories cannot be drawn into the pressure laboratory, and an explosion in the cubicle should not significantly affect the make-up air ductwork.

Negative pressure is maintained in the laboratory and the barricade to prevent escape of toxic and/or flammable vapors into other parts of the Hazardous Operations Building and to diminish the possibility or the effects of a secondary explosion. Figures 2 and 3 show that the top of the truncated trapezoidal roof of the barricade is welded to a 16 in. i.d. steel elbow (0.375 in. wall) that extends outside through the paneled glass. The outer end of this elbow is covered with a 4-mil polyethylene blow-out panel, which also serves as weatherproofing. A 16 in. i.d. side arm, welded to the elbow, connects to the inlet of a 3000 cu ft/min, spark-resistant exhaust fan (Buffalo Forge Limit Load), which discharges through heavy louvers. An alarm is sounded if air flow through the exhaust system is insufficient to produce a preset differential pressure in an explosion-proof switch.

### Cylinder and compressor area

The cylinder yard is located directly behind the plastic blow-out panel. A 1 in. steel cable blast mat 7.5 ft × 6 ft is hung from heavy pipe supported in concrete in front of the panel. Compressed gas cylinders and a double-end compressor are housed in the cylinder yard in ventilated light wooden sheds. Oxidizing gases are separated from reducing gases by a metal partition and provision is made to chain each cylinder. The compressor is separated from the gas cylinders by a masonry partition.

## Compressor and accumulators

Factory modification of an Aminco double-end diaphragm compressor (2 cu in.) enables simultaneous compression of two separate gases without contamination (*11*). A hydraulic relief valve limits gas pressure to 11 500 psig. Each suction side of the compressor is connected with a Pressuretrol switch that is set to shut the compressor should suction pressure fall below 700 psig, the minimum required to raise discharge pressure to 10 000 psig. Most users recognize the need for a pressure switch on the discharge side of compressors but it is equally important to maintain positive pressure on the suction side, especially when compressing explosive gases, to prevent intake of air from a leak. The discharge sides of the compressor are equipped with air-operated valves that are normally closed. The discharge lines from the compressor to the accumulators and the air lines for the air-operated compressor valves are shown entering the laboratory in Figure 4.

The compressor has proven to be practically maintenance free, owing to the inclusion of 3 $\mu$ gas filters in the suction side.

The accumulators (316SS, 2 liter, 10 000 psig), which also act as dampers, are located inside the barricade (Figure 2), behind a 1 in. cable blast mat. Each was hydrostatically tested (16 500 psig, 70 °F). All high-pressure lines, including those from both accumulators, are equipped with excess surge check valves. If these lines rupture, the valves prevent escape of large volumes of gas into the barricade. The discharge side of each accumulator is fitted with a normally closed air-operated valve. In addition, two high-pressure gauges with electric-contact faces, contained in modified surplus safety switch enclosures, are mounted inside the cubicle. The electric-contact gauges are set at the desired maximum and minimum pressure. In operation, they bring the compressor on line at the minimum set pressure and shut it at the preset higher pressure.

The two individual gases may be pumped simultaneously, regardless of compressibility or difference in suction pressures, with up to 10 000 psig in each accumulator. The first gas to reach the preset pressure in its accumulator will recycle until the second gas is compressed to its desired pressure in the companion accumulator. At this point the latching relay circuit shuts the double-end compressor and closes both air-operated valves on the suction side. The air-operated valves on the discharge side of the accumulators are normally closed. This automatic charging of the accumulators is usually conducted at night. The operator can then charge the reactor with gases from the accumulators or pressure burette.

## High-pressure reactors

A small-pressure laboratory is limited in the variety of reactors that may be accommodated. These units should be chosen to maximize versatility with regard to volume, temperature and pressure, and compatibility with chemicals to be contained. Our facility contains a modified (Autoclave Engineers, Inc.) 1 liter reactor for investigative purposes, a 2 gal reactor for scale-up (Figure 5), a 1 liter, 6000 psig Hastelloy C reactor, and a 30 in. tubular reactor (0.5 liter).

Records of pressure testing of reactors in addition to failure and repair data are kept for later evaluation.

Our smallest reactor is a 1 liter, 10 000 psig, 316SS vessel with a modified Bridgeman seal useful to 650 °F (Figure 6). It is equipped with an externally driven magnetic agitator (Magne-Drive), a Dispersimax stirrer, a pressure gauge, a thermowell, and a sampling tube in the cover. A gland retainer surrounding the top of the cover contains four 0.25 in. ports; one port connected to a sampling tube, two ports for a cooling coil, and the remaining port assigned to a gas inlet or vent line. The sampling tube in this reactor was too small (0.083 in. i.d.) for introduction of solids. Stock vessels normally require disassembly for introduction of solids, but we modified the reactor to include four 0.375 in. ports spaced around the circumference near the cover. One port fitted with a 0.375 in. rupture assembly connects to a 3 in. outside vent stack through a short piece of 0.5 in. i.d. tubing without sharp bends. Any of the three remaining ports can be used to introduce solids or, for sample removal, a design improvement that avoids disassembling the vessel. In case of disc failure, the contents are safely discharged into a collection unit maintained outside the building. The vent stack may subsequently be cleaned by a steam purge. Feed and product lines are connected to the ports as needed.

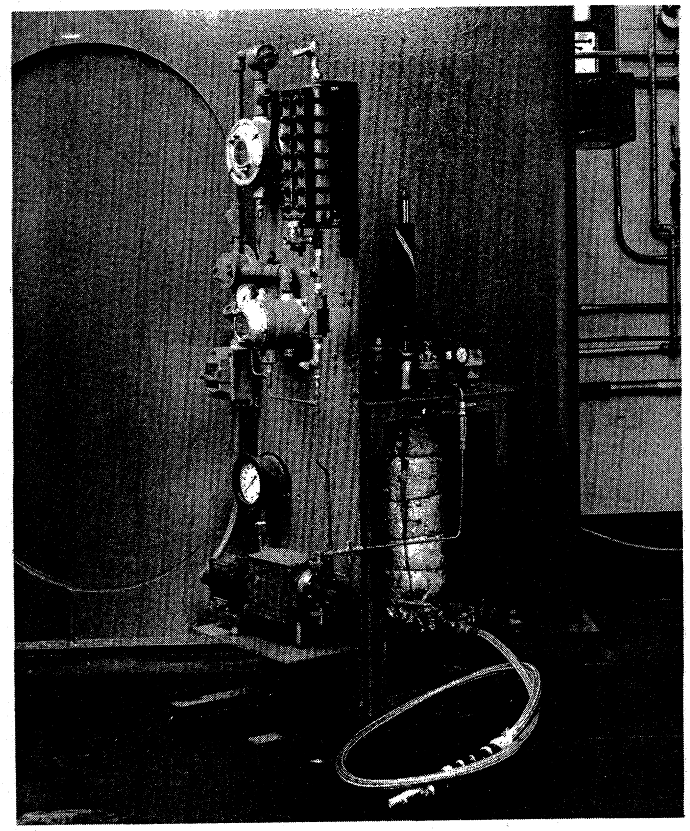

**Figure 5.** Two gallon stirred-tank reactor and associated controls

Limiting charge size and use of a corrosion-resistant rupture disc compatible with the expected reaction pressure is of prime importance, a precaution carelessly or naively disregarded by many operators. For example, a reaction done at 1000 psig generally requires a disc rated at 1300 psig. A disc with too high a pressure rating for reaction conditions may result in damage should a runaway reaction occur (*9*), especially in a larger reactor, if the time for pressure relief is over-long. One common failing is to use a gauge whose maximum reading is below the pressure rating of the disc. More than gauges can be lost this way.

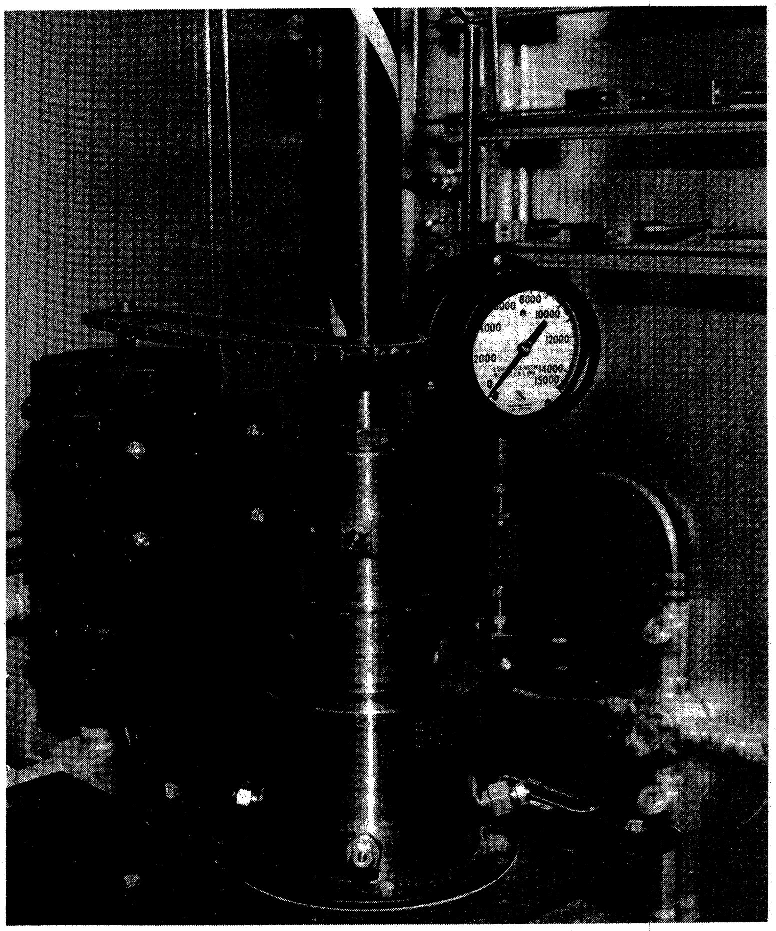

**Figure 6.** One liter, 10 000-psig reactor with modified Bridgeman seal

All high-pressure connections are made with cone and collar fittings. Valves are rated at 30 000 psig and have non-rotating stems to prevent galling the seats. The valves are bolted to welded Unistrut inside the barricade. All gauges are protected from surges with micrometallic snubbers. Reactors are mounted well away from the barricade wall to diminish the chance of missile penetration of the wall (*12*).

A 600 ml, 5000 psig burette is used to measure liquid reagents into the autoclave. An accurately calibrated 500 ml high-pressure gas burette, attached to Unistrut within the cubicle, is used to mix gases and measure their uptake. The high solubility of some gases in some solvents precludes using the autoclave directly as an accurate measure of the gas introduced. Although one can guesstimate gas loading by pressuring a known volume head space with the agitator off, one should always take account of gas nonideality in quantitative work. Our pressure burette can be connected to one of several large precision gauges. (Again it is important that the Bourdon tube of a gauge not be the weakest component of a pressurized system.) A tee in the line from the pressure burette to the reactor is connected to an explosion-proof pressure transmitter that affords instantaneous recording of the burette or autoclave pressure.

Usually the reactor is cooled before venting and care taken to avoid loss by entrainment. The connection of a spare vent line to one of the ports is always a wise precaution.

Bypass valves are installed so that equipment may be isolated for maintenance without discharging the remaining system. The valves mounted within the barricade are easily operated from the outside by means of extension rods protruding through the wall. (We prefer this to using long valve stems that can become missiles.)

**Reactor for pilot-plant processing**

The 2 gal stirred-tank reactor built in-house (Figure 5) was originally constructed for scale up of isopropenyl stearate, a development of our laboratory (see *Reactor Application*). It can also be used in sequential, automatically controlled batch reactions. It is a single-walled 304SS rated at 800 psig 70 °F, steamed traced and covered with Thermon cement. The insulation is wire wound to prevent dislodgment, since an explosion could blow away loosely fastened lagging, and fire heating the unwetted surface of the reactor could cause its failure.

The reactor is equipped with an air-driven Magne Drive unit fitted with a Dispersimax stirrer. A mirror in the barricade shows the operator the tachometer, gauges, and valve position. A stainless steel head gasket is used for sealing. (When working with acetylenic chemicals (*13*), such as MAPP gas, copper and its alloys must be rigorously excluded.) A pressure gauge, blow-leg, cooling coil, thermowell, baffle, blow-out disc and remotely controlled relief valve are incorporated in the reactor. An electric switch thermally actuated by a bulb embedded in the reactor sheath permits pumping a liquefied reactant gas only when the reactor temperature is above a preset value. An erratic steam supply could lower reactor pressure. The reactor pressure switch would then bring the liquefied MAPP compressor on line and cause premature opening of the relief valve. Temperature control of the reactor is provided by a pressure-reducing valve in the steam line and by use of a cooling coil. A tee in the bottom of the reactor is connected to two valves, one of which is fed from a steam kettle containing the charge, and the other goes to a product recovery line.

The system is equipped with a calibrated pressure burette that is connected in sequence to a filter, a Pulsafeeder pump, an outlet tee bearing a pressure gauge, and a bleed valve. The liquefied gas line, leading to the bottom of the reactor, is interconnected with the burette through a ball check valve with an 8 psig cracking pressure. Two explosion-proof switches are connected in series for control of the pump pressure: one switch closes when sufficient nitrogen pressure to prevent vapor lock is indicated; the second interrupts operation of the pump when a preset reactor pressure is reached. The reactor is mounted on a portable stand for operation inside the cubicle (Figure 5). It is equipped with pneumatic valves and can be tied into the purged operator control panel.

Connections for instrumentation, utilities, feed, and product recovery lines are brought to the reactor with flexible quick-connects. In the event of a failure in utilities, a manual overide affords control of the stirrer with a reserve air cylinder. Restoration of utilities must be accompanied by manually resetting the electrical circuitry to place the control panel in "go".

**Hastelloy C Reactor**

A 1 liter (Autoclave Engineers Inc.), 6000 psig reactor with bolted closure and magnetic stirrer is used with corrosive chemicals such as hydrogen chloride.

It is essential that people involved in the design and operation of high-pressure reactors continuously evaluate all aspects of stress, corrosion, and hydrogen embrittlement that may cause system failure (*14–18*). The selection of materials of construction and an understanding of their behavior in normal use, in cyclic operation, and during shutdown is an important factor in arriving at final specifications for a safe, practical reactor.

### Control panel

The operator's control panel (Figures 1 and 3) complies with OSHA requirements (NFPA code 496) for Type X purging. This padlocked NEMA 12 control enclosure was specifically designed for easy maintenance, convenience, safety, and facile control of pressure equipment and the recording of reaction parameters. This steel cabinet, 3 ft × 3 ft × 1.7 ft is wall-mounted adjacent to the barricade with the panel face in perpendicular alignment to the barricade face (Figure 3), permitting the operator to observe both the equipment inside the barricade and the control panel.

All control circuits to the barricade are interlocked with failsafe devices. The circuits that must be clear before the operator's control panel shows "go" are:

1. The enclosure purge cycle must be completed and have at least 0.1 in. water pressure at a fixed flow.
2. The barricade microswitch must indicate blast-resistant door completely closed.
3. Air at a fixed differential pressure and rate must be exhausted through the barricade and create a slight negative pressure within.
4. The automatically controlled Air-Lec operated door must be in the fully open position.
5. The switch in the reactor heater shroud must indicate the proper flow of nitrogen.
6. Reactor temperature and pressure must be at or below the set temperature and pressure.
7. The gas detectors must indicate less than 5% of the lowest explosive level of certain gases.
8. The ambient temperature in the barricade must be below 130 °F.
9. Deionized water must be able to flow at a controlled rate through the reactor cooling coil as shown by an indicating light.

Failure to set any of these conditions in "go" triggers an audible alarm and a red indicating light on the panel.

Heat control to the reactor furnace is provided through a four-function current-adjusting controller and the SCR power unit; a high limit set point in the recorder-controller prevents temperature overshoot, and automatically triggers the cooling system. Thermocouple burnout automatically interrupts electrical input to the furnace. (It's a good idea to install a spare couple and bring its leads out of the barricade.) In the event an exothermic reaction exceeds the reactor temperature set limit, the heating load is automatically interrupted and deionized water is admitted to the cooling coils. (Untreated water can precipitate salts that clog the flow indicator and cooling coil.) The operator can control cooling water and agitation through a manual override. *A thermocouple adjacent to the heating element controls the temperature gradient through the wall of the autoclave. Using it for primary control maintains nicely isothermal conditions in the autoclave.* Heating the autoclave is automatically interrupted and an alarm sounded when the pressure limit setting is exceeded. A back-pressure regulator automatically begins to relieve this pressure. Reactor heating can be resumed only when the alarm is silenced, the problem corrected, and the reset circuit engaged. A 120-h timer is included in the circuitry for around-the-clock operation. This interlocked control system has performed reliably and safely.

Simple access to all components is another hallmark of our control panel in contrast to typical panels. The latter are generally constructed of a 0.25 in. steel plate, about 2 ft in front of the barricade. Valve handles extend through the plate and recording, monitoring, and control equipment, with assorted plumbing and electrical wiring, are mounted with indicating lights and alarms. The inaccessible location of this array of connecting tubing and wiring behind the panel hinders trouble shooting. The barricade is useless until the trouble can be located and corrected from the outside. Our electrical controls, pressure and temperature recorder, and sensing equipment are mounted within the control panel. A SCR drive for the autoclave furnace, relays, motor control, push buttons, indicating lights, and all electrical equipment in the panel are wired to terminal blocks. Each circuit is clearly marked and easily traced to aid in trouble shooting. The double-pen recorder controller has been provided with extra set-point and limit switches along with spare relay terminals for future additions to the circuitry. The variable speed roll chart improves recording of reaction parameters.

### Using the 2 gal reactor to make isopropenyl esters

The 2 gal reactor has been used for the batch preparation of 30 gal of the isopropenyl esters of long-chain fatty acids (*19–25*). These highly reactive intermediates have been synthesized at our pressure facility for development of their industrial applications. The esters are exceptionally stable to moisture and heat on long-term storage. They show unusually interesting applications as acylation agents, having the advantage of forming acetone as an innocuous byproduct compared with fatty acyl chlorides, which require base neutralization of the hydrogen chloride produced.

Isopropenyl stearate (IPS), an important example of these compounds, is prepared simply by reaction of stearic acid with MAPP gas in the presence of a zinc salt catalyst (zinc stearate). MAPP gas is an approximately 33 mol % methylacetylene–33 mol % allene concentrate containing a butane-propane-propylene diluent for stabilization. The diluent also ensures that the concentration of methylacetylene-allene remains nearly constant during the vaporization (weathering) of the mixture. The feed and product are nontoxic and the process is nonpolluting. The yield is typically 94–97% of theory.

$$R{-}CO_2H + CH_3{-}C{\equiv}CH \xrightarrow{Zn^{++}} R{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}O{-}C(=CH_2){-}CH_3$$

The scale up of IPS was done in the 2 gal reactor after tying it into the barricade utilities and controls. The lines and valves were steam traced to prevent solidification of feed or product. The reactor was preheated to 200–220 °F and charged with a molten stearic acid–20% zinc stearate mixture. The charge filled the reactor to 65% of capacity at reaction temperature. The reactor was pressure tested with dry nitrogen at 400 psig and then vented and purged three times with dry nitrogen at 400 psig and the pressure released. While being stirred, the charge was heated to 300 °F and the pressure increased to 400 psig with MAPP gas (U.S. Bureau of Mines Report No. 3849). Isopropenylation was complete in 1.75–2 h under these conditions. Control of the reaction was maintained by infrared spectroscopy and the process repeated uneventfully for production of 30 gal of crude IPS. The crude IPS containing zinc catalyst was passed through a Turba-Film Processor. This afforded purified IPS as a white product in the overheads with recovery of the reusable zinc stearate catalyst in the bottoms. By material balance, about 66% of the feed was recovered as overheads during the first pass. The second pass yielded an additional 13% in the overheads. An acceptable throughput of 48 lb/h sq ft was established. MAPP gas is nontoxic in the concentration encountered during normal plant operation. Its explosive (flammable) limit is within the range of propane, propylene, and natural gas (*26*, *27*).

## Safety

Operating personnel must be familiar with the properties of the chemicals, the equipment and the instruments involved, and they must follow recognized practices with no "short cuts". Personnel should be familiar with sources of safety information (*28*).

The laboratory is equipped with protective and first aid equipment, namely, fire blankets, fire extinguishers, a standpipe, safety showers, an eye fountain, gas masks, safety masks, goggles, demand air packs, a fire suit, ear muffs, and conductive safety shoes. Ear drums, sinuses, and lungs may be damaged from blast over pressure, so ear protection is a minimum safety requirement. These precautions have further included installation of explosion-proof telephones.

## Costs and savings

A cost estimate of $150 000 had been received for construction of a pressure laboratory based on our design. Since this greatly exceeded our budgetary resources, construction was largely undertaken in-house at a total cost of $55 000. A cost breakdown is given below.

| | Cost |
|---|---|
| 1. In-house costs: shops personnel, designing, engineering, drafting, procurement and prorated scientists' salaries | $20 000.00 |
| 2. Contracted costs (installed): includes fire extinguishing system, exhaust system, barricade, cylinder yard, and conductive floor | 10 000.00 |
| 3. Pressure equipment, ancillary equipment, electrical equipment, reactors, accumulators, and compressor | 25 000.00 |
| | $55 000.00 |

In Table 1, a partial list of items comprising the third group is compared to more costly alternatives to show typical savings.

**Table 1.**

| Purchased and installed in-house | Cost[a] | Contractor alternatives | Cost[a] |
|---|---|---|---|
| Steel barricade | $3700 | Concrete | $9000[c] |
| One modified double-end compressor | 2500 | Two compressors | 4600 |
| Control panel: in-house fabrication and assembly | 5000 | Contractor estimate | 10 000 |
| Explosion-proof lighting fixtures | 1000 | Similar fixtures | 2100 |
| Explosion-proof gauges[b] with contact faces | 400 | Commercial gauges with contact faces | 1600 |

[a] Costs in the period 1970–1972. [b] Gauges installed in available surplus explosion-proof switch enclosures. [c] Low bid, includes extended footing on a sand back-fill and a steel spall plate.

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