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PROJECT ENGINEERING
of Process Plants

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To our wives

for their patience and help

CHAPTER 24

SAFETY IN PLANT DESIGN

Safety must be a paramount consideration in the design of a process plant. The mass of steel that is fashioned into a plant will ultimately be operated by human beings whose health and well-being must be protected.

Disregard of safety in the design of a process plant is comparable to criminal negligence. Each design engineer should feel a responsibility for providing a safe design. He should ask himself: "Would I be willing to operate this equipment as it is now designed?" If the answer is "no" or if the "yes" is weak, the reasons for the uncertainty should be found and corrected. The designer should, whenever possible, discuss his design with operating men and the plant safety engineers. These men are keenly aware of safety and will have many good suggestions.

HAZARDS IN PROCESS PLANTS

The hazards to be considered in the design of any process plant can be grouped roughly into three major categories: flammable and explosive, hygienic, and mechanical. A majority of chemical processes are potentially dangerous because flammable and explosive materials are produced. The design of equipment for such plants must be dictated by characteristics of the materials being processed. One's memory on the combustion characteristics or explosive limits of materials should never be trusted. Careful investigation of these characteristics of the materials to be handled in the plant should precede all design calculations.

A number of chemical products constitute definite health hazards. Prolonged breathing and/or skin contact over a long period of time of such materials as benzene and carbon tetrachloride can cause permanent impairment of health or even death. It is surprising that many scientifically trained people are unaware of the hazards to health presented by some common chemicals. Although there are excellent references on industrial toxicology which can be used as guides, all but the most common chemicals should be referred to a trained industrial toxicologist for study before handling techniques are devised.

Mechanical hazards include all the hazards created by moving equipment and arrangement of equipment and structures.

These classifications are somewhat arbitrary and overlap, but they serve to emphasize the primary hazards in process plants that create or are capable of creating unsafe working conditions.

Careful design combined with well-planned accident prevention programs have produced amazing safety records. Manufacturers of tetraethyl lead, for instance, were faced with an unusual health problem due to the poisonous nature of the raw materials and product. Realizing this problem even before the design of the plant was begun created an awareness that influenced all design decisions. The result has been an enviable record of safe operation.

Sources of Information

Many safe practices are no more than application of common sense. The problem is to recognize unsafe situations before they are incorporated in plant design. Basically, this involves determination of the hazards that exist. In addition to many books on safety and industrial hygiene,[1,2,6,11,12,13] there are a number of handbooks, codes, and similar publications by numerous agencies interested in safety and fire prevention which are helpful in defining potential hazards. A selection of these is given below:

I. Fire and explosions

1. National Fire Protection Association; 60 Batterymarch Street, Boston 10, Mass.; a nonprofit technical and educational organization; publishes:

a. Standards: widely adopted throughout U.S.A. as basis for construction. Following summaries of standards are available.

(i) National Fire Codes for Flammable Liquids, Gases, Chemicals and Explosives.

(ii) National Fire Codes for the Prevention of Dust Explosions.

(iii) National Fire Codes for Building Construction and Equipment.

(iv) National Fire Codes for Extinguishing and Alarm Equipment.

(v) National Electrical Code.

b. Quarterly of the National Fire Protection Association: up-to-date information on fires and fire prevention.

c. NFPA Handbook of Fire Protection: a handy reference work.

2. National Board of Fire Underwriters, 85 John Street, New York 7, New York; an educational, factual and engineering organization supported by the capital stock fire insurance companies publishes:

a. Standards for fire protection many of which are based on NFPA standards.

b. Research reports.

c. Special reports on unusual disasters. (Most of this information is sent free of charge upon request on company stationery. Advice and counsel on certain phases of fire protection problems not now covered by codes or standards can be obtained.)

3. Other insurance organizations: The Factory Insurance Associaton, 555 Asylum Street, Hartford 2, Conn.; Associated Factory Mutual Fire Insurance Company, 184 High Street, Boston 10, Mass. These also operate research laboratories and publish standards.

4. Federal Agencies, Washington, D.C.

a. 1. U.S. Bureau of Mines—research reports and recommendations, minerals, dusts, and oils.

b. U.S. Dept. of Agriculture; dust explosions and fires.

c. U.S. Dept of Labor, Division of Labor Standards; safe practices recommended for various industries.

d. National Bureau of Standards; fire hazards and fire resistance research.

e. U.S. Public Health Service; industrial hygiene publications.

5. National Safety Council, 20 N. Wacker Drive, Chicago, Ill.; mainly safety education. Research work conducted-advice available (nonprofit).

6. Underwriters Laboratories, Inc., 207 E. Ohio Street, Chicago 11, Ill.; (nonprofit). Tests equipment (electrical, fire protection, etc.) to insure safety. Lists of tested and approved equipment issued annually with bi-monthly supplements.

7. Laws; federal, state, and local laws relating to fire protection and buildings. Many refer to various provisions of the NFPA codes.

8. Insurance companies and local and state fire prevention bureaus can provide valuable advice.

9. American Petroleum Institute, 50 W. 50th Street, New York, N.Y.; publishes bulletins on *Fire Protection in Refineries.*

II. Industrial hygiene

1. Manufacturing Chemists' Association; publishes chemical safety data sheet for the safe handling and use of many chemicals.

2. National Safety Council; publishes health and safe practices pamphlets relative to the handling of various chemicals.

3. American Industrial Hygiene Association; publishes technical quarterly on industrial hygiene.

4. U.S. Bureau of Mines, Washington, D.C.; dusts and toxic vapors.

5. Atomic Energy Commission, Washington, D.C.; radioactive materials.

6. Mellon Institute, Industrial Hygiene Foundation, Pittsburgh, Pa.; research.

7. Division of Industrial Hygiene, U.S. Public Health Service, Washington, D.C.; publications of various types and advice.

8. American Medical Association, Committee on Physical Agents of a Hazardous Nature.

9. Chemical companies; publish information on the safe handling of their own products. Producers of tetraethyl-lead, for instance, recommend and furnish complete design for equipment handling the ethyl fluid.

10. Sax, N. I., *Handbook of Dangerous Materials,* Reinhold Publishing

Corp., N.Y. (1951); gives hazardous properties, treatment, and antidotes; also suggestions for safe handling of numerous toxic materials of commerce.

III. Mechanical

1. Equipment manufacturers; will recommend safe installation procedures.
2. U.S. Department of Labor, Division of Labor Standards; publications on safe practices and recommendations for industry.
3. National Safety Council; safe practices, recommendations, presented in pamphlets.
4. Codes for construction of vessels, tanks, piping, electrical equipment:
   a. ASME and API-ASME Codes for Unfired Pressure.
   b. ASME Boiler Construction Code.
   c. American Standards Association Code for Pressure Piping.
   d. API Standard No. 12C and 12E for Storage Tanks.
   e. National Electrical Code.
5. Liability insurance companies; publish helpful data which aid in the design of safe plants.

PLANT LAYOUT

The safety record of a plant depends partially upon the arrangement of the various units and the location of equipment within those units. For this reason alone safety considerations should permeate even the early planning stages of plant design.

Topography and Weather

In selecting a site topography and meteorological phenomena should be carefully considered. Hilly areas present certain inherent hazards. Overflowing tanks or vessel failures can send thousands of gallons of flammable materials into surrounding areas. If the area is hilly, these materials can reach a wider area and if ignited cause a rapid spread of fire.

Prevailing winds should be considered in the layout of a plant so that flammable and toxic gases can be properly dissipated without endangering the lives or comfort of plant personnel or people in the surrounding areas.

The occurrence of such weather phenomena as inversions should be analyzed. The atmospheric temperature normally decreases with altitude. During periods of inversion the reverse is true. In such situations the lower atmosphere remains stagnant, and smoke and noxious vapors hang over the earth's surface and create extreme health hazards. The DeNora, Pennsylvania disaster in which a number of people died was caused by such a condition. Any area that has frequent inversions lasting more than three to four days should be rejected as a possible site for a process plant.

Division of Plant into Units

The operating units of a process plant should be separated not only for more efficient operation and maintenance but also for safety reasons. By separating the process units it is possible to prevent the spread of fire and explosion.

Dividing a plant into city-type blocks has many advantages. The blocks are usually separated by roadways making access to all parts of the plant convenient. These roadways may vary from 50 to 100 ft in width. Dead-end roads should be avoided and convenient access from any part of the plant should be possible in at least two different directions.

Although roads provide a definite service to the plant, they also can constitute a safety hazard if they are not properly arranged. Many serious fires and explosions have been caused by vehicles striking tanks or vessels containing flammable materials. The possibility of such accidents should be considered in planning roadways.

In Table 24-1 some suggestions are made for spacing between process units and other facilities in a plant. Any such list to be complete would be extremely voluminous since each type of process unit should be considered individually.

TABLE 24-1. Suggested Minimum Spacings for Hazardous Process Units

Description of hazard	Distance to adjacent operating unit, ft
1. Ordinary flammability and low to medium pressures	25–75
2. High flammability and high pressure	100–150
3. Direct fired boilers and furnaces	100–150
4. Blowdown stacks with flare	100–200
5. Loading facilities	100
6. Public roads and railroads	100
7. Cooling tower	100
8. Storage tanks*	75–150

* Minimum distances between storage tanks are given in the National Fire Codes.[10] Wherever possible a distance equivalent to 1 or 1½ times the diameter of the larger tank should be used.

Utilities

The generation and distribution of utilities in a process plant is such an important function that these facilities should be located as remotely as practicable from the operating units. During emergencies caused by fire or explosions, the continued operation of the power plant, the water pumping station, and the steam generating unit is imperative. Open flames and sparking equipment are common in power plants and boiler houses, and location near a unit processing flammable products constitutes a real hazard.

Buildings

Plant offices, mechanical shops, and laboratories should be located as far as possible from the operating units. There is no real need for proximity of offices to process units, and since open flames and sparks are common to both shops and laboratories it is also advisable to separate these buildings from the process units.

Warehouse and loading facilities should be located at the plant property line so that they are easily accessible from the public roads and are as far as possible from the areas of possible danger.

Equipment Layout

A primary rule for equipment layout is that an operator should have at least two different routes of escape from any point in a unit. Extremely hazardous areas should be provided with escape chutes for rapid exit from the area.

Since a clean well-maintained area is often a safe area, equipment must be arranged to enable ease of maintenance and housekeeping.

Equipment should be located well above the average height of a man or considerably below since any location near usual height can result in frequent head injuries. As a rule the simpler the arrangement, the safer the unit. A simple arrangement facilitates prompt action in emergencies.

Firewalls

When it is necessary to space units closer than is considered safe, shielding walls can be constructed of concrete. High walls of this type are also used to protect personnel from operating equipment which could explode or cause a severe fire.

Dikes or firewalls should be provided around all storage tanks containing flammable material. These walls are especially necessary for flammable materials which tend to boil over. In these cases, the firewall should be high enough to contain the entire contents of the tank and thus prevent the spread of fire to other tanks or other portions of the plant. Rules and suggestions for firewall construction have been outlined in detail.[5,8,9]

Units processing large quantities of flammable material are often paved and enclosed by low walls 12 to 24 in. high. Should a vessel rupture, these walls will contain the flammable material and prevent the spread of fire. In some process areas the sewage system can be designed to drain off such spillages rapidly in which case firewalls are not needed.

MECHANICAL DESIGN AND SAFETY

To insure safe construction all mechanical design should be in accordance with existing codes. All practices important to safe design, however, are not specified by the codes. Some of the more common practices are listed below in the form of a safety check list for designers.

A. Vessels and tanks

1. Careful selection of materials to withstand corrosion. Use adequate corrosion allowances on materials that are expected to corrode.

2. Provide a sufficient number of manholes and handholes for inspection and maintenance, and orient to permit easy access.

3. Avoid screwed nipples for small nozzles. Use 6000 lb couplings.

4. Nozzles above 1½ in. should be flanged. For high pressure, use flanged nozzles for all sizes.

5. Careful inspection during and after fabrication; a competent inspector can do much to prevent vessel failures.

a. Inspection of materials.

b. Inspection of workmanship (especially quality of welds).

c. Witnessing of radiographing and stress relieving.

6. Atmospheric storage tanks should be provided with adequate vents for breathing (the taking in or discharging of vapor as the pressure in the tank increases or decreases due to change in temperature or liquid level).

a. Use vacuum-pressure breather valves (conservation vents).

b. Use floating-roof tanks for volatile liquids.

c. Connect vapor spaces of gas-tight tanks to a single tank serving as a gas holder. Provide relief valves for all tanks, however.

7. Automatic totally enclosed tank level gages preferred; manual gage hatches subject operator to needless hazards.

B. Heat exchangers

1. If both inlet and outlet of exchanger require block valves, provide relief valve on cold side to prevent excessive thermal expansion. Many explosions have occurred because of such expansion.

2. Sufficient drains should be provided for maintenance.

3. Each fluid space of an exchanger should be given an individual test.

4. If units are to be stacked, they must be stacked during the testing process.

5. If mixture of shell and tube fluids constitutes a hazard, extreme care in design and workmanship must be exercised.

C. Moving equipment (pumps, etc.)

1. Provide guards at all couplings, belts, and chain drives.

2. Provide adequate space between units for safe and convenient servicing.

3. Automatic overload, overspeed, or other devices are good investments on machinery such as compressors.

4. Protective devices such as strainers on pumps and liquid knockout drums for compressors are essential to safe operation.

D. Piping

1. Above-ground process lines are preferred. These may be elevated or placed at ground level on sleepers. Buried lines constitute a hazard since leaks are not readily detected.

2. If lines are installed in trenches, fire stops and drains must be provided at regular intervals.

3. Arrangement of piping and valves is important to safe operation.

a. Large valves in particular must be readily accessible from platforms. Approximately 7 ft 0 in. is the maximum distance from centerline to platform level. Above this chain operators are used.

b. Use double-block valves for hazardous equipment which must be removed while remainder of unit continues to operate. A small tell-tale valve in between double blocks indicates leakage.

c. Arrange long yard lines to avoid congestion so that in case of fire any portion can be isolated from the remainder by closing a block valve.

d. Headroom for overhead lines should be approximately 15 ft 0 in. above roads; 6 ft 6 in. above platform; 9 ft 0 in. above grade. If a line must be located below 6 ft 6 in., locate considerably below and provide a walkway over it.

e. Fuel supply valves for furnaces should be in a remote location.

f. Emergency dump valves should be located at a safe distance from the equipment to be dumped and preferably behind a heavy wall or building.

g. Install valves discharging into open tanks so that operator can operate without undue exposure to vapors or splashing.

4. Check valves leak; and if such leaking is intolerable, provide a block valve in addition to the check valve.
5. Avoid angle valves.
6. For structural reasons avoid pipe smaller than 1 in. for overhead lines.
7. Drains for low points and vents for high points should be provided. Use ¾ in. or larger sizes.
8. Water lines, especially fire lines, should be looped.
9. Loop steam lines and provide block valves so steam can be provided from several directions in case of failure of one portion of the system.
10. Separate sewer systems may be necessary for certain hazardous materials. Venting of such systems must be carefully planned.
11. Fire stops are necessary in all surface drainage systems to prevent spread of fire.
12. Lines should be pressure tested prior to operation. Care must be taken to avoid overstressing certain pieces of equipment or foundations during hydrostatic tests.

E. Electrical equipment and grounding

The safe installation and design of electrical equipment is carefully outlined by the *National Electrical Code*. The problem requires the attention of competent electrical engineers. They must be supplied with information on the hazards in each part of the plant.

1. Means for remote shut-down of operating equipment in addition to locally mounted starters is desirable.
2. Critical items such as switchgear and transformers should be located as remotely as practicable from operating units.
3. Identify underground conduit by including a dye in the concrete for the casing.
4. Protect overhead conduit from exposure to excessive heat.
5. Provide emergency power supplies.
6. All portions of the plant must be adequately lighted so that operators can avoid bodily injuries from bumps or falls.
7. Static electricity and lightning constitute real hazards to safe process plant operation. Neither can be prevented but protection is possible. Watch for static electricity accumulation and discharges in the following situations:

   a. Moving machinery (belts, conveyors, etc.).

   b. Flowing fluids or dust.

   c. Human beings.

   d. Lightning.

Protection is accomplished by proper grounding of all equipment in areas where static electricity is anticipated. When all metal equipment rests on concrete foundations, for instance, grounding must be installed. Instructions for proper grounding of equipment are given in Handbook of Fire Protection,[8] the National Electrical Codes, and various government publications[9] (See also sources of information).

F. Structural steel

1. Protect from failure due to fire by covering with concrete to the main support level or by providing emergency water sprays for cooling steel in event of fire.

2. Avoid interferences of structural steel with piping and equipment. Interferences are sometimes remedied in the field by removing or "cutting-out" portions of steel, thereby reducing the strength of the structure.

3. Platforms should be provided at all operating or inspection areas with a 2 ft 6 in. minimum width. 3 ft to 3 ft 6 in. is preferred in maintenance areas around manholes.

4. Stairways are preferable to ladders and at least two are required for larger units. Use gentle slope, 45° or less, and widths of 3 ft 0 in. or more.

5. Safety cages are required for ladders over 15 to 20 ft.

6. Handrails are required around all platforms and stairways.

7. Toe plates (6 in. high) around the edges of platforms are necessary to protect personnel from falling objects.

G. Buildings

1. Fireproof construction is essential in hazardous areas.

2. Unless absolutely necessary process equipment should not be housed. Operation of outdoor plants is much safer.

3. Provide explosion doors to handle any possible explosions that may occur.

4. Provide automatic sprinkler systems when practical.

5. At least two exits are required.

H. Insulation

1. Insulate all hot lines with which personnel may come in contact. Approximately 1 in. to 1½ in. of 85% magnesia is adequate for protection of personnel. More, of course, may be required for heat conservation. Detailed specifications are available from insulation manufacturers.

2. Insulate portions of critical instrument leads and electrical conduit in areas of excessive heat or areas where fire is probable.

VENTILATION

When process equipment must be located indoors, ventilation becomes a major problem. Both toxicity and flammability of a material must be considered in design of a ventilation system.

Toxic Concentrations

Materials such as aniline, the halogens, hydrogen fluoride, and phosgene are toxic in concentrations as low as 5 parts per million, whereas toxic concentrations of such familiar materials as ammonia, benzene, chloroform, hydrogen sulfide and carbon tetrachloride range from 20 to 100 parts per million. Maximum allowable concentrations of various chemicals have been published as tables.[2] The user of such tables should be cautioned, however, that research on toxic properties of some materials is incomplete, and, as new information becomes available, the values of allowable concentrations may be revised either upward or downward.

Limits of Flammability

Information on flammability limits of gases and vapors and methods of estimation have been published.[3,11,15] The limits of flammability are expressed as upper and lower limits. The lower limit represents the least amount of the material which will sustain flame propagation when mixed with air, and the upper limit represents the greatest amount. These limits of flammability as determined experimentally are affected by the type of testing apparatus used. Extremely small apparatus in particular produces narrow limits of flammability, and results from such equipment should be used with caution. The flammability limits for mixtures of several combustible gases and air can be estimated from an equation which has been verified experimentally:

$$L_m = \frac{100}{\dfrac{C_1}{L_1} + \dfrac{C_2}{L_2} + \dfrac{C_3}{L_3} + \cdots}$$

where L_m = limit of flammability of mixture. Mole % (upper or lower)

L_1, L_2, L_3 = limits of flammability (upper or lower) for gases 1, 2, and 3, mole % (e.g., moles of gas/mole of gas plus air)

C_1, C_2, C_3 = mole % on air and inert free basis of gases 1, 2, and 3

The units of this expression are consistent since the summation of C/L terms has units of moles of air plus moles of combustible per mole of combustible.

Required Ventilation Rate

Knowing the rate of release of hazardous vapor and the allowable concentration of contaminate in an enclosure, the minimum fresh air rate can be calculated from a simple material balance.

$$\frac{r_V}{r_A + r_V} = \frac{L_A}{100}$$

where r_V = moles of contaminate entering enclosure per unit time

r_A = moles of fresh air per unit time

L_A = lower flammability limit or toxic limit whichever is smaller, mole % contaminate per mole of air plus contaminate

The practice of expressing ventilating capacity in air changes per hour should be avoided. If 15 air changes per hour proves the correct air rate for one installation, it does not follow that this same rate will produce satisfactory results in an enclosure of smaller size.

$$\left(\text{Air changes} = \frac{\text{Air rate, cu ft/hour}}{\text{Enclosure volume cu ft/change}}\right)$$

Local Ventilation

General room ventilation can be supplemented by localized ventilation over the equipment from which offending vapors are being emitted. Such local units are arranged as exhaust systems, and consist of hoods designed to catch the maximum amount of vapor or dust without interfering with the operation or servicing of the equipment. Hoods can be placed over filters, at pump packing glands, around crushing and grinding operations, and at other similar installations.

Positive Air Pressure

It is often desirable to maintain a higher air pressure in a hazardous area than in the surrounding rooms or the outdoors. The electrical equipment, for instance, which cannot be designed for explosion-proof operation can be installed in a hazardous area by placing it in a room under positive air pressure.

Inert Gas Purge

The use of inert gas is another valuable aid to ventilation. Inert gas is manufactured by burning fuel gases in conventional furnaces or, preferably, specially designed inert gas generators. The gas can be used to purge tanks and vessels of toxic and flammable vapors before purging with air so that men may enter the vessel.

Men have died after entering inefficiently purged equipment. Every process plant which handles toxic or flammable materials must be equipped with inert gas generators or air or steam eductors for removing the toxic vapors and flammable vapors from tanks and vessels which must be entered by personnel.

Ventilation for Comfort

In addition to removing flammable or toxic materials generated in enclosed areas, ventilation and conditioning of the air in operating buildings is also important to workers' comfort and morale. It may be considered safe for men to work under hot and humid or extremely cold conditions, but the worker's efficiency and dexterity are reduced under such conditions and accidents may develop merely because of fatigue, discomfort, or low morale.

Design of Ventilating Systems

In process plants extreme care should be exercised in locating inlet and exhaust ducts to avoid short-circuiting of fresh air (entrance of fresh air into exhaust ducts). The degree of mixing of the toxic or flammable gas with the room air must be known in order to decide upon location of exhaust openings.

If possible, vapors removed from rooms should be treated before releasing to the surrounding atmosphere. Centrifugal or cyclone separators, spray or packed columns, air filters, and electrostatic precipitators can render exhaust gases less objectionable. In any event, the gases should be discharged from the building in the same direction as the prevailing wind. Revolving type roof ventilators permit such a discharge even with variable winds.

PRESSURE-RELIEVING DEVICES

It is impracticable to design process equipment for every possible condition that may arise through abnormal situations. Fortunately, however, abnormal situations can be handled by the use of pressure-relieving

TABLE 24-2. Conditions Requiring Relieving Devices

<table>
<tr><th>Condition</th><th>Design Basis</th></tr>
<tr><td>Failure of cooling water supply to fractionating tower</td><td>Vapor equivalent to maximum total overhead rate</td></tr>
<tr><td>Failure of fractionating tower reflux</td><td>Maximum possible flow equivalent to total overhead rate</td></tr>
<tr><td>Entrance of foreign highly volatile material</td><td>Calculate vapor flow based on instantaneous vaporization</td></tr>
<tr><td>Exposure to fire</td><td>1. Calculate heat input on basis of PAW data which in equation form becomes approximately:
$$\log q = (0.796) \log S - 1.7$$
where q = heat input to vessel in millions of Btu per hour
S = surface area exposed to flame in sq ft
2. Use for exposed surface area
<table>
<tr><td>Horizontal vessels less than 20 ft in diam</td><td>One-half cylindrical surface plus area of heads</td></tr>
<tr><td>Horizontal vessels more than 20 ft in diam</td><td>All area up to 20 ft above ground</td></tr>
<tr><td>Vertical vessels less than 20 ft high</td><td>All circumferential area plus bottom head</td></tr>
<tr><td>Vertical vessels greater than 20 ft high</td><td>Lower 20 ft of area</td></tr>
</table>
For insulated vessels (2 in. fireproof insulation or above) reduce calculated input by 20%</td></tr>
</table>

TABLE 24-2. Conditions Requiring Relieving Devices (continued)

Condition	Design Basis
Exposure to fire (*continued*)	3. Calculate vapors generated $$W = \frac{q}{H}$$ where W = lb/hr vapors H = latent heat (Alternate method) $$W = \frac{\left(\frac{q}{S}\right)(S)}{H}$$ Use q/S = 22,000 This alternate method is far more conservative than the PAW method. Other methods give intermediate values.
Closed valves	Amount of fluid leaving vessel under normal operating conditions
Thermal expansion of confined liquids	$$W = \frac{Bq}{C_p}$$ where B = coefficient of thermal expansion, $1/T$ q = heat supplied to fluid C_p = heat capacity W = lb/hr
Thermal expansion of confined gases	Calculate increase in volume using Gas Laws
Excessive heat loads during abnormal operation	Vapor generated by additional heat input

devices such as relief valves or rupture disks. The design of pressure-relieving systems requires careful study. In a badly planned system, too many or too few are installed or those installed are not well placed.

Sylvander and Katz[14] have prepared an excellent discussion on the design and construction of pressure-relieving systems. Some typical applications for relieving devices are given in Table 24-2, with suggested design basis for each application. This table is based in part on the work of Sylvander and Katz.

Discharge Rates of Relief Valves and Rupture Disks

The rate of discharge for a relief valve or rupture disk is calculated by the following formulas for vapors and liquids. The vapor formula is derived assuming an ideal gas, adiabatic expansion, a value of 1.001 for the ratio of specific heats, and vapor flowing at the acoustic velocity. Higher values of specific heat ratio will give a lower discharge rate; and, therefore, the simplified formula given below is conservative. The formula for liquids is based on the simple orifice equation. Manufacturers furnish handy charts and tables which facilitate the calculations of relief valve and rupture disk sizes.

Discharge rates of relief valves and rupture disks

Vapor:

$$W = 315APC\sqrt{\frac{M}{T}}$$

A = area of orifice, sq in.
P = upstream pressure, psia
C = nozzle coefficient, 0.97 for relief valves (10% accumulation), 0.81 for rupture disks (consult manufacturer)
M = molecular weight
T = absolute upstream temperature, ° F

Liquid:

$$Q = 38AC\sqrt{\frac{\Delta P}{S.G.}}$$

Q = liquid capacity in gpm
A = orifice area, sq. in.
C = coefficient of discharge, 0.40 for relief valves (10% accumulation), 0.61 for rupture disks
$S.G.$ = specific gravity

Relief and Blow-down Discharge Systems

The proper disposal of materials discharged by automatic relieving devices or manually operated blow-down valves is an important phase of plant safety. Relief valves which are located on top of high fractionating towers can often be vented to the atmosphere. Such atmospheric venting, however, is not always possible when large quantities of flammable vapors or liquids must be discharged at a safe distance from the plant for disposal. The discharges of relief valves and blow-down valves can be manifolded into a single discharge line connected to the disposal section (a burning pit, flare stack, or a quench tower).

If there is a large area far enough from the process section and smoke is not objectionable to the surrounding community, burning pits with pilot flames can be employed for the disposal of both flammable liquids and gases. As industrial areas grow and plants expand, however, the burning pit becomes more and more objectionable.

Flare Stacks

Flare stacks are constructed of pipe or boiler plate of sufficient diameter to satisfy the overall pressure-drop requirements for the system and high enough that the burned vapors will not constitute a nuisance or hazard and will be diffused readily by the prevailing winds. The stacks usually range in height from 100 to 200 ft.

A knock-out or entrainment separator is installed for the separation of liquids contained in the vapor stream. The gases then pass through a seal drum, the inlet of which extends below a water or oil level in the drum. The gas bubbles through this liquid and then enters the flare stack. The sealing liquid prevents flame flash-back from the flare. The upper 8 to 10 ft of the flare stack is best constructed of an alloy such as Type 304 stainless steel since this upper portion becomes extremely hot and ordinary steel will not withstand the high temperature.

A pilot light is provided at the top of the flare which burns continuously and is thus able to ignite gases as they escape. To prevent extinguishment of the pilot flame, a mixture of air and gas is piped to the pilot so that a strong, blue flame will result. This flame is difficult to observe from the ground, however, and an additional small luminous burner is also used so that a ground observer can easily detect failure of the pilot. The pilot is lighted by a sparking device inside of the pipe through which the mixture of gas and air travels to the top of the flare. The flame is, thereby, propagated to the pilot. Other methods are used. One employs a series of gas jets located inside an open pipe spaced at regular intervals starting at the location of ignition and terminating at the pilot.

Quench Towers

Large amounts of hot heavy liquids can be discharged to a quench tower where condensation of a majority of the liquids will take place. The small amount of vapor yet remaining can be vented to the atmosphere or to a flare stack depending upon its quantity. The heavy liquids can be recovered in an oil separator.

Relief Valve Piping

Relief valves should be installed so that they are easily accessible for servicing. Dual relief valves can be employed so that one may be serviced while the other is in place for operation. In such installations plug cock valves* are installed on the inlet side of the relief valve and arranged with an interlocking mechanism so that one valve must be opened when the other is closed.

Piping upstream from the relief valve should be as short as possible to avoid excessive pressure drops. The pressure drop in the suction line should not exceed one per cent of the allowable pressure for full capacity relief. Discharge piping should also be designed to prevent excessive pressure drop, and for most installations the pressure drop should not exceed 10 per cent of the set pressure of the relief valve. The line should never be smaller than the outlet size of the relief valve. The discharge piping must be well supported at all points of strain, especially that produced by the impact of the discharging gases.

Common relief valve and blown-down headers should slope gradually toward the knock-out drums so that liquids may readily drain from the system. Pockets in discharge lines cannot be tolerated. Discharge lines venting to the atmosphere must be provided with weather protection to prevent accumulation of water in the vertical pipe. Steam snuffing lines venting to the atmosphere are also needed so that discharging gases might be diluted to prevent ignition. The steam can also be used in case of fire in the discharge line.

Though relief and blown-down systems are vital, an overdose of caution in their design may result in a costly and cumbersome system. Each section and item of equipment must be considered separately and the most probable abnormal condition or conditions selected for the design basis. Careful consideration will usually show that all possible abnormalities will not occur simultaneously on one item of equipment or one section of the plant. Experience plays an important part in such decisions and the engineer should seek the advice and counsel of the safety department of his organization.

FIRE EXTINGUISHING EQUIPMENT

Extinguishing process plant fires is a highly specialized type of fire fighting, the know-how for which has evolved from long experience. Fortunately most of the useful regulations that aid in the selection and application of fire fighting equipment have been published by such agencies as American Petroleum Institute, National Fire Protection Association, National Board of Fire Underwriters, and others (see section on sources of information). As well as taking advantage of such information, the project engineer should obtain the advice of men skilled in the art before attempting the design of fire extinguishing facilities for a process plant.

* Gate valves are also used.

Water as a Fire Extinguishing Agent

Water continues to be the major fire fighting agent, and its uses expanded after the introduction of water fog nozzles and sprinkler systems. A steady stream of water on a flammable liquid often does more harm than good, but the use of a fog or mist of water which tends to smother the fire in addition to producing a cooling effect has proved extremely successful.

The great dependence upon water as a fire fighting agent suggests the careful planning of fire water distribution systems. Such a system invariably requires fire pumps to boost the normal water pressure to the higher pressures required for the fire hose and sprinkler systems. Fire pumps must be carefully selected and have an alternate drive to insure operation under the most adverse conditions. A typical dual drive fire pump is equipped with an electric motor and a gasoline engine drive. The gasoline engine is used during power failure.

Other Extinguishing Agents

Another common method of extinguishing fires quickly in confined areas is by smothering the fire. This can be done by the use of foam or inert gases such as carbon dioxide. Steam smothering is also valuable and is particularly useful in extinguishing small fires around furnaces.

Emergency Valving

Main shut-off valves for lines carrying flammable materials should be located so they can be operated in case of fire. It may be preferable in some fires to simply stop the flow of flammable material and allow that already escaped to burn. This avoids large concentrations of explosive gas and vapor.

Portable Extinguishers

In addition to the permanent installations of fire hydrants, automatic sprinkler systems, and automatic carbon dioxide extinguishing systems, portable fire extinguishers should be supplied throughout a process plant since a small fire can often be extinguished with ease by the rapid use of an extinguisher. Most large fires begin as very minor conflagrations, and immediate attention to a small fire will often prevent a disaster.

Selecting Fire Extinguishing Equipment

The project engineer should be cautious in using handy fire extinguishing tables designed to indicate the exact extinguishing method for various types of flammable material. They give general suggestions and are not intended to be specific for all situations. These tables can be a helpful guide, but advice of authorized agencies should be obtained.

When a new plant is being designed all materials which constitute a fire hazard in the operation of the plant should be carefully studied. Case histories of previous fires for similar plants should be obtained so that fire extinguishing equipment can be intelligently selected and placed. The National Board of Fire Underwriters, The National Fire Protection Association, The Associated Factory Mutual Insurance Agency, and other such groups will supply reliable information of this type.

Plant Alarm System

An alarm system should be installed in all process plants so that personnel can be alerted in case of fire. In most plants the alarm system can be manual, although in some process areas normally requiring little attention, automatic alarm is preferable.

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