Safe Practices Pamphlet No. 34

Industrial Explosion Hazards

Gases, Vapors and Flammable Liquids

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This pamphlet is one of more than 150 Safe Practices and Health Practices Pamphlets. It is a compilation of experience in accident prevention from many sources. It should not be assumed, however, that it includes every acceptable procedure in the field covered. It must not be confused with American Standard safety codes; federal laws; insurance requirements; state laws, rules and regulations; and municipal ordinances. *Additional copies of this pamphlet are available. Member price, 75 cents each. Quantity and non-member prices on request.*

1. A serious danger to employees and property in many industries is the use, creation or accidental occurrence of gases, vapors and liquids that may cause an explosion. This danger exists, often unsuspected, in so many plants that it is desirable for every executive to give some consideration to conditions in his own plant and to take steps to prevent fires or explosions before something occurs to call this danger more forcibly to his attention.

2. An explosion from a chemical viewpoint is most commonly a rapid chemical reaction, such as combustion or decomposition, that causes a great and sudden evolution of gases, or heating of gas, or a combination of these. There is an attending sudden violent increase of pressure, usually accompanied by a sharp report, and explosion waves are set up in the air and other associated material. While the term "explosion" is employed in this pamphlet to include only rapid chemical reactions that produce a sudden violent increase in pressure, it should be recognized that violent explosions of a physical nature can be caused by a sudden release of gases and vapors under pressure, such as the bursting of a steam boiler or other pressure vessels. It is also possible to create destructive or physical conditions of an explosive nature by chemical or physical reactions that produce a partial or complete vacuum in a confined space, as the sudden condensation of steam in a vessel or the chemical reaction of gases that form products occupying less space than those that entered into the reaction. In these situations the explosion and accompanying destruction arise from the fact that the walls of the space or vessel are forced in by the external normal pressure of the atmosphere which at sea level is 14.7 pounds per square inch.

While not many explosions of this nature occur in industrial equipment, they are possible. However, they frequently occur in the laboratory, when working with glass vessels.

3. The violence or destruction that accompanies or immediately follows most explosions is due, primarily, to the development of pressure that ruptures the walls of the space in which the exploding substance is confined, or to explosion waves and vibrations set up with the exploding substance. Following an explosion and the original outrush of air, there is a reversal and air rushes back to the area. This causes a partial vacuum in the surrounding area that may be strong enough to pull windows out or even cause walls to be sucked over. Also, explosions of volatile materials are commonly accompanied by flame and subsequent fires and by destruction due to objects and debris set in motion by the forces created. (See Figure 1.)

4. Explosives may be divided into the following four general classes:

I. Explosive substances.

a) Commercial explosives or chemical explosives (discussed in Safe

Figure 1. A fire and explosion in Chicago [illegible] with [illegible] and the [illegible] with [illegible]

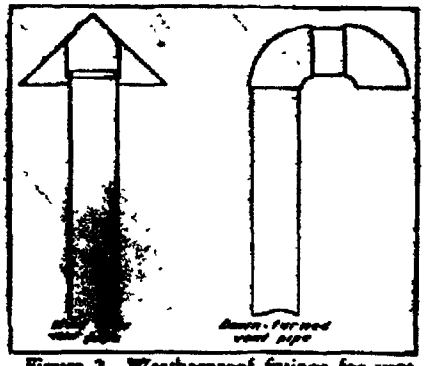


Figure 2. Weatherproof fittings for vent pipes. (See paragraph 23d.)

Practices Pamphlet No. 28), such as dynamite and gunpowder, which contain the oxygen necessary for their rapid combustion, or, where the weak chemical bonds of the nitrogen in the compound are easily broken by a chemical or physical shock.

b) Chemicals not used as commercial explosives but which can decompose spontaneously (such as acetylene.)

II. Gases and vapors which react rapidly with gases (other than oxygen) when they are ignited by heating or sunlight. Examples are chlorine and hydrogen or bromine and fluorine.

III. Combustible dusts (discussed in Safe Practices Pamphlet No. 104), which may or may not contain enough oxygen for rapid combustion. They are explosive when mixed in proper proportion with air.

IV Combustible gases and vapors from flammable liquids, when they are mixed intimately in certain proportions with air or other oxygen containing gases from which they obtain the oxygen necessary for rapid combustion (ammonia, illuminating gas, gasoline, naphtha and practically every other flammable gas, vapor or liquid.)

5. This pamphlet contains a discussion of the substances included in the third of these three major classes, namely, gases, vapors, and flammable liquids. *Consideration of flammable liquids, however, is limited to the contribution they make to explosion hazards by the flammable vapors that are given off by such liquids.* It should be recognized that there are explosion hazards from liquids other than that of their vapors; some liquids can decompose rapidly enough to cause an explosion or they can decompose and form gaseous products that are explosive. For example, nitro-glycerine is an explosive liquid but gasoline is a flammable liquid whose vapors when mixed with air and ignited in a confined space can produce explosions. In the one case, sudden violent decomposition or explosion is caused merely by detonation or sudden shock, while in the case of gasoline it is only the vapors that will explode. Nitroglycerine is an explosive liquid but gasoline is a liquid whose vapors will burn or explode when mixed with air in the proportion of 1.4% to 6%. Certain other mists or fogs (air-carried droplets or particles of liquid rather than vapors), are explosive in much the same manner as dusts or particles of combustible solids. Mist explosions will even occur where the liquids are not volatile enough to produce explosive amounts of vapor at ordinary room temperatures.

6. The most unstable of all commercial combustible gases is acetylene which will dissociate, (split into its component parts, hydrogen and carbon) if subjected to heat when it is at more than atmospheric pressure. It is for this reason that the gas, when stored under pressure, is compressed in vessels containing a porous substance that will prevent dissociation or explosion. In actual practice this porous material is soaked with a solvent, such as acetone, that will absorb many times its own weight of acetylene.

7. A number of rather common gases will react with each other with explosive violence in the absence of air or oxygen. Mixtures of chlorine and hydrogen will react violently, the product of the reaction being hydrogen chloride. Also, while the reaction in mixtures of hydrogen and chlorine may be initiated with a flame, the mixtures are very unstable or sensitive; the reaction may be started by sunlight. Likewise chlorine will react violently with gases and vapors such as acetylene, ethylene and other hydrocarbons especially of the unsaturated types. Other combinations of gases, particularly the other halogens as bromine and fluorine, are violently reactive but the foregoing will illustrate that hazards of explosions of gases and vapors are not confined to those that form flammable mixtures with air or oxygen.

8. From a hazard standpoint, mixtures of gases that are unstable and very sensitive to ignition by moderate heat or by spontaneous processes are more dangerous than either those that require a positive source of ignition such as a flame or spark or those that react immediately on contact. When positive ignition is required the mixtures are safe [illegible] such an ignition source is present. [illegible] the case of unstable mixtures the [illegible]gerous mixture can accumulate and the reaction may then take place spontaneously.

9. The group of gases and vapors that are flammable and will produce explosive mixtures with air or oxygen has the broadest interest from an industrial explosion hazard viewpoint. The number of gases or vapors in this group is so large that it is not practicable to give a complete list in this pamphlet. In general, however, a complete list would include every gas that is combustible and every liquid that is volatile enough to create a flammable vapor mixture with air. The list may also include substances that alone are not volatile enough to create a flammable vapor air mixture, but which will contribute a significant amount of vapors to combustible gases or vapors from other sources so that the mixture of vapors as a whole makes a flammable vapor-air mixture. For example, if there were three liquids either as a mixture, or separately, each of which was volatile enough to give off only one third the amount of vapors required to form an explosive vapor-air mixture, the cumulative contribution of the three would be explosive. This will be discussed in more detail later under the subject of flammable limits of mixtures of vapors.

10. *Flash point:* This is the temperature at which a combustible liquid gives off enough vapors to be ignitable as determined by a prescribed test procedure. It provides a basis for classifying combustible liquids in accordance with their fire and explosion hazards. For information on the methods and apparatus for determining the flash point of [illegible] adopted by the American [illegible] Testing Materials, [illegible], Philadelphia, Pa., and [illegible] by the American Standards [illegible]

[illegible] the hazards of the [illegible] of flammable gases and vapors that form explosive mixtures with air and ways of preventing explosions, an understanding of some of the common properties of flammable

gases, vapors, and liquids is important. In this pamphlet it is not possible to indicate more than a few of these properties and point out their relation to explosion hazards and their control.

Explosive Gases

Acetylene (at pressures above atmospheric)

Combustible Gases

Acetylene
Ammonia
Butane (above atmospheric pressure)
Butylene
Carbon Monoxide
Coal Gas
Ethane
Ethylene
Ethylene Oxide
Hydrogen
Hydrogen Sulphide
Illuminating gas
Methane
Methyl Chloride
Natural Gas
Miscellaneous commercial fuel gases
Propane (at atmospheric pressure)
Propylene

Flammable Liquids

Class 1—Liquids in this class have a flash point below 25° F., closed cup tester

Acetaldehyde —17
Acetone 0
Aluminum Paint 0-25
*Benzine 0 or less
Benzol 12
Butyraldehyde greater than —20
Carbon Disulphide —22
Collodion 0 or less
Cyclohexane 1.
Cyclohexane Hexahydrobenzol
Denatured Alcohol (Govt. Formula SD-13A) lower than 19
Diethyl Ether —20
Ethyl Acetate —24
Ethyl Chloride —58
Ethylene Oxide lower than 20
Ethyl Ether 0 or less
Ethyl Formate —4
Ethyl Methyl Ether —35
Ethyl Nitrite —31
Gasoline —50
Gasoline (natural) 0 or less
Heptane 25
Hexane —7
Lacquer 0 to 80
Lactol Spirits 7
Leather Cement 0 or less
Methyl Acetate 15
Methyl Ether —42
Methyl Formate —2
Naphtha —0 or lower
Naphtha, V. M. and P. (Mineral Spirit) —40 to 20
Paint and Grease Eradicators 0-80
Paint, Bronze or Gold 0-70
Paint [illegible] 0 to 80
Pentane
Petroleum Ether —50
Propylene Oxide lower than 20
Propyl Ether (Iso) —18
Propyl Formate (Iso) —22
Propyl Formate (normal) 27
Vinyl Acetate —18
Vinyl Ether —20

Class 2—Liquids in this class have a flash point above 25° F., closed cup tester, and below 70 degrees F., closed cup tester.

Acetyl Chloride 40
Aluminum Paint 0-70
Butyl Acetate (Iso) 64
Butyl Formate 64
Croton Aldehyde 55
*Crude Petroleum
Denatured Alcohols 45 to 60
Diacetone (Technical) 40-57
Dichlorethylene 57
Diethylene dioxide 65
Ethyl Alcohols 48 to 65
Ethyl Alcohol & Water (up to 30% water) 62 to 70
Ethyl Benzene 59
Ethylene Dichloride 56
Ethyl Methyl Ketone 30
Ethyl Nitrate 50
Ethyl Propionate 54
Lacquer 0-80
Methyl Alcohol 54
Methyl Butyrate 57
Naphtha ("Solvent") Benzol (Coal Tar Naphtha) 60
Nitrocellulose (Wet with solvent) 40
Octane 56
Paraldehyde 63
Propyl Acetate 58
Propyl Acetate (Iso) 43
Propyl Alcohol (n) 59
Propyl Alcohols (Iso) 53
Propyl Alcohols (Sec.) 67
Propylene Dichloride 59
Pyridine 68
Rubber Cement 50 or less
Toluol 40
Varnish Shellac 40 to 70

Class 3—Liquids in this class have a flash point above 70° F., and below 200° F., closed cup tester.

Acetic Acid 104
Allyl Alcohol 70
Amyl Acetates 77 to 91
Amyl Alcohols 91-109
Aniline 168
Benzaldehyde 148
Benzyl Chloride 140
Brandy 84
Bromobenzene 149
Bronzing Liquid, below 80
Butyl Acetates 64-72
Butyl Alcohol 84
Butyl Alcohol (Iso) 82
Butylbenzene 126
Butyl "Carbitol" 172
Butyl "Cellosolve" 141
Butyl Ether 100
Butyl Lactate 160
Butyric Acid 170
Butyric Anhydride 190
Butyrone 120
**Carbon Remover Liquid
Chlor Benzol 82
Chloroethyl Acetate 129
**Cleaning Fluid
**Coal Tar Light Oil
**Coal Tar Oil
Creosote Oil 165
Cresol —0 to 178
**Crude Petroleum
Decalin 136
Decane 115
Diacetone (Acetone Free) 131
Dibutyl Ether 77
Dichlorethyl Ether (Chlorex) 172
Dichlorobenzene 150
Diethyl Carbonate 77
Dimethyl Aniline 145

Courtesy Sherwin-Williams Company

Figure 3. Belts equipped with metal-brush static electricity collectors. (See paragraph 35.)

*Distillate
Ethyl Acetanilide 126
Ethyl Alcohol & Water (more than 30% water) 72 to 144
Ethyl Butyl Acetate 135
Ethyl Butyl Alcohol 137
Ethylene Diamine 93
Ethyl Glycol 104
Ethyl Glycol Acetate 117
Ethyl Lactate 115
Fish Oil 150
**Flavoring Extracts
Formaldehyde 130
No. 1. Fuel Oil 100-165
No. 2. Fuel Oil 110-190
No. 3. Fuel Oil 125-200
No. 5. Fuel Oil 150 and over
No. 6. Fuel Oil 150 and over
Furfural 140
Fusel Oil 108
Gas Oil 150 and over
Hexyl Alcohol (n) 145
Kerosine 100-165
Lacquer 0-80
**Leather Dressing
**Liquid Metal Polish
**Liquid Stove Polish
Methyl Amyl Alcohol 113
Methyl "Cellosolve" 107
Methyl "Cellosolve" Acetate 132
Methyl Glycol 97
Methyl Propyl "Carbinol" 105
Nitrobenzol 190
Octyl Acetate 180
Octyl Alcohol 178
Octyl Aldehyde 125
Phenol (Carbolic Acid) 175
Pine Oil 172
Pine Tar Oil 144
Propylbenzol (n) 86
Pyroxylin Solution 80
Signal Oil 150
Stoddard Solvents (Naphtha High Flash) 300-[illegible] or higher
Toluidine
Turpentine
Turpentine Substitute 90
**Varnish
Whiskey 82
Wines (Sherry and Port) 129
Xylene 63

* May be below 25° F depending on specifications.

** May be below 70° F depending on specifications.

12. The above brief list gives the ash points of a number of the well known gases, vapors, and flammable liquids that are liable to cause an explosion. They were taken from the National Fire Codes for Flammable Liquids and Gases, published by the National Fire Protection Association and Factory Mutual Data Sheet No. 36-10, published by the Associated Factory Mutual. The flash points given in each case are the lowest shown in the reference material; reference should be made to these sources for flash points of materials not covered here. It should be borne in mind that flash points of any of the substances given may vary according to the purity. Where there is any doubt, either a test should be made to get accurate data on the substance used, or the lowest flash point given should be accepted as the probable correct value.

13. *Flammable limits.* Each flammable gas or vapor has two rather definite limits to the proportions in air that will propagate flame and become explosive. The "lower flammable limit" is the least amount and the "upper flammable limit" is the maximum amount that will propagate flame if ignited. Here it should be noted that the terms flammable limits and explosive limits are synonymous and each is frequently used although most references use the term explosive limits. The range of concentrations of gases between the lower and upper limits of the particular gas or vapor is its range of flammability or explosibility. When the amount of gas or vapor is below its lower flammable limit and a source of ignition such as a flame or spark is present, a small amount will be burned in the immediate vicinity of the flame or spark but the flame will not be self-propagating through the body of gas, but will be extinguished. When the igniting source is removed, the combustion will cease. In other words, there is no propagation of flame away from the igniting source. Likewise, when the material is above the upper flammable limit, there is some combustion if oxygen is present but the flame will not be self-propagating. In all proportions between the lower and the upper limits the mixture upon ignition at one point will propagate flame throughout the entire mixture. If a gas or vapor in air is kept below the lower limit concentration, there is no danger of an explosion; also if it is above the upper limit it will not propagate flame, but if it is above the upper limit and later becomes diluted with air or oxygen, it will fall within the flammable range. In most industrial situations where there are flammable gas or vapor hazards, the concentrations will vary from traces up through the full range of flammability to the source of the vapors where the amounts may be above the upper range of flammability.

14. Any variation in the amount of air present in a mixture will, of course, affect the ignition point of the mixture. When the particles of a gas are widely separated by an increased amount of air, the mixture is said to be too lean and flame will not propagate. While ignition might occur, it will not be supported since the particles of gas or vapor are too far apart for the initial flame to spread. Conversely when the mixture is deficient in air, the mixture is said to be too rich. Here the gas or vapor particles crowd one another so closely that there is insufficient oxygen to support combustion. Between the upper and lower limits of the explosion range are found all the graduations of slow or rapid combustion. This provides a commonly used basis for control of explosions, by maintaining the required deficiency of oxygen in the mixtures.

15. The slight normal changes of atmospheric pressure have little effect on the explosive range of gas or vapor and air mixtures. Marked changes up or down do, however, cause some change, this change being specific for each mixture. Decreases in pressure for the first few hundred millimeter below 760 cause only minor variation but as the pressure is further decreased the explosive range narrows until at a sufficiently low pressure the lower explosive limit coincides with the upper limit. Here no flame will propagate. Increased pressure, on the other hand, does not always increase the explosive range. In some mixtures the range is narrowed so that a mixture that will propagate at atmospheric pressure will not do so at a higher pressure. (For additional details on the effect of pressure on common gases see "Limits of Inflammability of Gases and Vapors," Bulletin 279, Bureau of Mines by M. G. Coward and G. W. Jones.)

16. Temperature variations within the range of room or living conditions have no practical effect on the range of flammability. However, a marked increase in temperature will have an appreciable effect. To propagate flame, the layer of unburned gas next to the burning layer must be brought to the temperature of ignition before it will burst into flame. If the unburned layer is already heated some degree, a smaller amount of heat has to be supplied from the burning layer and thus flame propagation will be aided. This elevation of temperature decreases the lower limit of flammability and raises the upper limit.

17. *Limits of mixtures of gases and vapors.* When two or more flammable gases or vapors are present in a mixture with air or oxygen, each gas makes its own contribution to the flammability or explosibility of the mixture. Each may be present in amounts below its lower limit but the total of the contributions of each may create an explosive atmosphere. A rather simple formula for estimating the probable explosive character of a mixture from the amount of each gas or vapor and its lower flammable limits was suggested by Le Chatelier. Investigations have indicated that this formula is correct for mixtures of hydrogen, carbon monoxide, and methane taken two at a time or all together, and for water gas and coal gas, also for the simpler paraffin hydrocarbons including natural gas. On the other hand there are some marked deviations with vapors such as ether and acetone. The formula is thus useful when its applicability has been proved but must not be used indiscriminately. In certain cases the law will not have commercial application since the normal variations in the major constituents of a mixture may make it unnecessary to consider the influence of minor constituents. For the purpose of this pamphlet it is sufficient to know that a general relation of this nature holds for the flammability of mixtures of combustible gases. A detailed discussion of the work that has been done on the application of the formula and manner of [illegible] the U. S. Bureau of Mines [illegible] 279, 1929 edition.

18. [illegible] Limits. In Table I [illegible] the lower and the upper flammable limits of some of the common gases and vapors when present as a single combustible constituent in air. While the values determined by various investigators for a particular

compound vary with the conditions of experiment, the values given in the table have been selected (Bureau of Mines Bulletin 279, 1939 edition) as those that would be most generally representative of the conditions of industrial situations. Small variations are of no consequence since in the control of explosion hazards a considerable safety factor should be used.

19. [illegible] *Temperature.* Reference is frequently made to the igniting temperature of a gas or vapor in air, with the understanding that it is the minimum temperature required to initiate an explosion. While it is true that gases and vapors have rather definite temperatures at which they become ignited in air, it must be remembered that in each case the recorded temperature of ignition is also closely related to the exact conditions under which the particular value was obtained. Ignition temperatures are not definite physical constants under practical conditions. The temperature that will produce ignition of the same gas or vapor may vary considerably for different means of ignition, particularly if they are heated surfaces. Catalytic effects are very important, particularly those of the type that accelerate surface combustion at comparatively low temperatures. This causes an increase in temperature of the igniting body, which in turn speeds up the reaction so that the surface temperature continues to rise until it becomes high enough to ignite the mixture.

20. The means by which explosions of gases and vapors may be initiated vary considerably with the particular gas or vapor dealt with and the conditions under which the explosions occur. With acetylene; for example, only pressure is required. With hydrogen and chlorine, strong light is sufficient. Mixtures of chlorine or bromine with acetylene require no initiator. Some gases such as phosphine ignite spontaneously and immediately on contact with air. Carbon disulphide vapors in air can be ignited by [illegible] at temperatures below visibly red heat, even high pressure steam lines. However, for the majority of gases and vapors, temperatures of around 750 to 900° C. and higher are required, depending on the particular substance. In addition to mere temperature of the igniting source, ignition of gases or vapors requires a certain quantity of energy. For example, elec-

Table 1

Summarized Data on Limits of Flammability of Gases and Vapors
Limits given in Per Cent by Volume, Moisture Free Basis

Gas or vapor	Limits in air, per cent		Limits in oxygen, per cent		Oxygen percentage below which no mixture is flammable	
	Lower	Upper	Lower	Upper	Nitrogen as diluent of air	Carbon dioxide as diluent of air
Acetaldehyde	4.0	57	..	..	...	...
Acetone	2.55	13	..	..	13.5	15.6
Acetylene	2.3	80	..	..	...	...
Allyl alcohol	2.4	..	..	..	...	...
Ammonia	16	27	15	79	...	...
Amyl alcohol	1.2	..	..	..	...	...
Amyl chloride	1.4	..	..	..	...	...
Amylene	1.6	..	..	..	...	...
Benzene (Benzol)	1.4	6.7	..	..	...	...
Butane	1.85	8.4	..	..	12.1	14.5
Butyl acetate	1.7††	..	..	..	...	...
Butyl alcohol	1.7	..	..	..	...	...
Butylene	1.7	9.0	..	..	...	...
Carbon disulphide	1.25	50	..	..	...	..
Carbon monoxide	12.5	74	..	..	5.6	5.9
Croton aldehyde	2.1	15.5**	..	..	...	...
Cyclohexane	1.3	1.2	8.3	..	...	...
Cyclopropane	2.4	10.3	2.45	63	...	...
Decane	.7	..	..	..	...	..
Dichloroethylene	9.7	12.8	..	..	...	...
Diethyl peroxide	2.35	..	..	..	...	...
Diethyl selenide	2.5	..	..	..	...	...
Dioxan	2.0	22**	..	..	...	...
Ethane	3.2	12.5	4.1	59	11.0	13.4
Ethyl acetate	2.0	11.5**	..	..	...	...
Ethyl alcohol	3.3	*19	..	..	...	...
Ethyl bromide	6.7	11.2	..	..	...	...
Ethyl chloride	4.0	14.8	..	..	...	...
Ethyl ether	1.85	48	2.1	82	...	...
Ethyl nitrite	3.0	..	..	..	...	...
Ethyl formate	2.7	16.5**	..	..	...	...
Ethylene	2.75	29	2.9	80	10.0	11.7
Ethylene dichloride	6.2	15.9**	..	..	...	..
Ethylene oxide	3.0	80	..	..	..	...
Furfural	2.1†	..	..	..	...	...
Heptane	1.0	6.0	..	..	...	...
Hexane	1.2	6.9	..	..	11.9	14.5
Hydrocyanic acid	5.6	40	..	..	...	...
Hydrogen	4.0	74	4.0	94	5.0	5.9
Hydrogen sulphide	4.3	45.5	..	..	..	..
Iso-Amyl alcohol	1.2	..	..	..	...	...
Isobutane	1.8	8.4	..	..	...	...
Iso-Butyl alcohol	1.8	..	..	..	...	...
Isopentane	1.3	..	..	..	...	...
Iso-Propyl acetate	1.8	7.8**	..	..	...	...
Iso-Propyl alcohol	2.6	..	..	..	...	...
Lead tetraethyl	1.8	..	..	..	...	...
Methane	5.0	15	5.4	59	12.1	14.6
Methyl acetate	3.1	15.9**	..	..	...	...
Methyl alcohol	6.7	*36	..	..	10.8	13.5
Methyl bromide	3.5	14.5	..	..	...	...
Methyl butyl ketone	1.2	8**	..	..	...	...
Methyl chloride	8.0	19	8.8	[illegible]	...	...
Methyl cyclohexane	1.2	..	..	[illegible]	...	...
Methyl ethyl ether	2.0	10.1	..	[illegible]	...	...
Methyl ethyl ketone	1.8	10	..	[illegible]	...	...
Methyl formate	5.0	23**	..	[illegible]	...	...
Methyl propyl ketone	1.5	8.5**	..	[illegible]	...	...
Naphtha	1	..	..	[illegible]	...	...
Octane	.95	..	..	[illegible]	...	...
Paraldehyde	1.3	..	..	[illegible]	...	...
Pentane	1.4	7.8	..	[illegible]	12.1	14.4
Propane	2.4	9.5	..	[illegible]	11.4	14.3

(Continued on next page)

Table 1

(Continued from page 5)

	Limits in air, per cent		Limits in oxygen, per cent		Oxygen percentage below which no mixture is flammable	
	Lower	Upper	Lower	Upper	Nitrogen as diluent of air	Carbon dioxide as diluent of air
Propyl [illegible]	1.8	8.0**	..	..	...	...
Propyl [illegible]ol	2.5	..	..	..	...	..
Propyl[illegible]	2.0	11.1	2.1	53	11.5	14.1
Propyl[illegible] dichloride ..	3.4	14.5**	..	..	...	...
Propylene oxide	2.1	21.5	..	..	...	...
Pyridine	1.8	12.4	..	..	...	...
Tin tetramethyl	1.9	..	..	..	...	...
Toluene	1.3	6.7	..	..	...	...
Vinyl chloride	4.0	22.0	..	..	...	...
Vinyl ether	1.7	27	1.8	85	..	...
Xylene	1.0	6.0	..	..	...	...

*At 60° C. **At 100° C. †At 125° C. ††At 30° C

tric sparks, even though at high temperature, can be so small and of such short duration that they do not burn enough of the gas or vapor-air mixture immediately surrounding them to start a general flame propagation through the mixture. However, ordinary sized sparks and small arcs such as are usually produced by electric switches, flame of matches, etc., are sufficient from a practical explosion hazard viewpoint to immediately ignite any flammable mixture of a combustible gas or vapor in air.

21. *Volatility.* The amount of vapor that will accumulate in the air above a volatile liquid is dependent upon its vapor pressure. Vapor pressure, sometimes called vapor tension, is a determinable physical property of all liquids and for a particular liquid it is affected only by changes in temperature. Vapor pressure values as given in standard tables usually are calculated at a temperature of 0° C. and 760 m.m. pressure (atmospheric pressure) hence, the vapor pressure at normal workroom or higher temperatures will vary. When the air space above a volatile liquid is saturated [illegible] that is when all the space is occupied by vapor, then the vapor is exerting its maximum pressure at that temperature and no more vapor will form. This fact is useful in determining the maximum amount of vapor that could be present if the air was saturated under the particular temperature and use of the substance. Another physical property of value in determining the relative volatility of substances is their boiling points. These, too, can be found in standard reference tables.

22. *Surface evaporation.* An important factor related to evaporation is the amount of surface exposed from which vapors may emanate. Evaporation takes place at the surface and, for example, if a gallon of liquid were exposed with a liquid surface of but one square foot the rate of evaporation would be roughly only one-tenth that of a gallon of liquid exposed under conditions of 10 square feet of surface. This is very important from a safety standpoint and points to minimizing surface areas as a means of control of hazards. The temperature is also very important as the potential rate of evaporation increases with an increase in temperature, owing to the increase in vapor pressure. Many substances will not give off enough vapors at ordinary temperatures to be explosive but will give off explosive amounts if the temperature is raised. A limiting factor exists in that the space over the liquid will eventually become saturated with vapor, especially if the space is confined, as in a partly filled, closed container. Thus at any given temperature a condition of balance is reached and evaporation no longer occurs. Materials in mist form present very favorable conditions for rapid evaporation, as the surface exposed is the total of the surfaces of the individual particles of mist.

Preventing Explosion

23. Explosions can be prevented (1) by preventing the development of explosive mixtures and (2) by preventing the ignition or setting off of the explosive mixture. Important steps in carrying out these measures are:

a) Making a thorough survey and inventory of products and processes to determine the possible ordinary and accidental sources of explosions or fires.

b) Reducing the possibility of occurrence of hazardous conditions to a minimum by such common procedures as substitution of non-explosive or less explosive products; isolation of dangerous products; improved safety in handling and use of volatile materials; good local and general ventilation; use of closed containers; use of inert gases to suppress flammable conditions and elimination of sources of ignition. (Cognizance should be taken of the toxicity of the materials used. In some cases it may be possible to substitute a less toxic as well as a less volatile material.)

c) Making thorough inspections at scheduled intervals.

d) Designing new plants so the effect of an explosion will be localized. (Explosion resisting partitions should separate hazardous and non-hazardous departments; all stair wells and elevator shafts should be completely enclosed, all pipe holes through walls and floors should be sealed and any other floor or wall opening should be closed to prevent the propagation of flame beyond the immediate site of the fire or explosion. Large outside window spaces should be provided and scored glass should be used to relieve the explosion pressure. Vent pipes should be installed.)

24. *Common ignition sources.* The ignition of an explosive mixture of gas or vapor with air may be prevented by the proper control of flame, fire, friction, sparks, static electricity, electric arc, excessive heat or spontaneous ignition.

25. *Smoking.* Many explosions have been caused by smoking and the throwing aside of lighted matches, cigars, pipe ashes, and cigarettes. Smoking, and the lighting or carrying of matches, cigar lighters, and other flame-producing articles, should be prohibited in every plant where explosive substances are used, stored or [illegible].

26. [illegible] clothing. In locations where the [illegible] of an explosion is especially [illegible] may be advisable to provide [illegible] clothing for men to wear when at work, this clothing being made entirely without pockets. At the entrances to all buildings or rooms where explosive substances may be present, danger signs should be posted, telling of the hazard, warning against the carry-

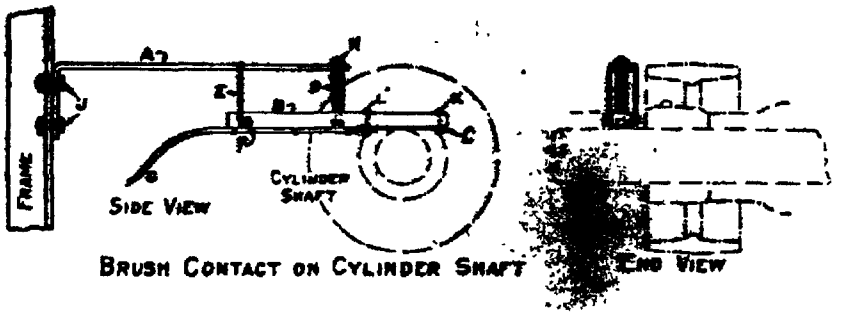
Table 2

Approximate Limits of Flammability of Some Industrial Mixtures of Gases and Vapors in Air at Ordinary Temperatures and Pressures, per cent

Gas or vapor	Lower Limit, by volume	Upper Limit, by volume
Benzol (Benzene) ..	1.1	8
Gasoline	1.4	6.5
Water [illegible]	6 to 9	55 to 70
Natural [illegible]	4.8	13.5
Illuminating gas ...	5.3	31
Blast-furnace gas....	35	74

The limit figures in Table 2 apply only to particular samples of mixture. By the use of Le Chatelier's law (see paragraph 17) the limits of samples of similar mixtures can be calculated.

Much more information is given in Bureau of Mines Bulletin 279, 1939 edition, on the conditions under which the values given in Table 1 and 2 were obtained as well as data on the limits of other gases, vapors and mixtures. The information pertains not only to limits when the gases or vapors are in air but also to other atmospheres, such as those that have either a deficiency or enrichment of oxygen, or the presence of carbon dioxide or other gases that have a suppressing effect on the propagation of flame.



BILL OF MATERIAL

	No. Pcs Req'd	Name	Size	Material
A	1	Bracket	⅜" x 1"	W. I.
B	1	Brush Holder	⅝" x 1" x ⅝"	Hard Wood
C	1	Brush	3" x 1"	Copper
D	1	Brush Spring		Steel
E	1	Wire Support		
F	1	Fulcrum Pin	⅛" x 1½"	W. I.
G	1	Lead to Ground-Insulated	No. 14 G	Copper
H	1	Spring Bolt	¼" x 3"	
J	2	Machine "	⅜" x 1"	
K	1	R.H. Stove "	⅜" x 1"	
L	1	" " " "	⅜" x 1½"	

Figure 4. Brush contact for removing static from shafting. (See paragraph 35.)

ing of matches or open lights, and prohibiting the entrance of unauthorized persons.

27. *Open flames, lanterns, boilers, etc.* The use of open flames, such as lanterns, gas jets, oil lamps, torches, or candles, should not be permitted in plants where there is an explosion hazard. Neither should boilers, furnaces, or dryers with open flames be installed in those portions of the plant where explosive substances may be present. Gases and vapors may be carried by drafts to a flame several hundred feet away. Heavy vapors may spread across a floor or table to a flame and may flash back and cause an explosion at the point from which the gas or vapor originated. Boilers and other fires should be in separate buildings without connecting tunnels or enclosed walkways and out of the line [illegible] which explosive gases and vapors might travel or be blown by prevailing winds. The plant layout should conform with state or local requirements. Welding operations are a source of open flame. Before any welding or cutting is done, systems should be purged of all flammable liquids, vapors or gases. Tests using a flammable gas indicator should be made to determine whether or not it is safe to weld or cut.

28. *Fire hazards.* Fire is a serious hazard in practically every industrial establishment, but it is particularly dangerous in a plant where there are flammable gases and vapors because any accidental fire is almost sure to cause an explosion. Accordingly, in such a plant, every possible precaution should be taken to prevent fire and to extinguish it immediately if one should occur. These problems are discussed in other sections of this pamphlet; also in Safe Practices Pamphlets No. 24, "Fire Extinguishment," No. 31, "Fire Causes and Prevention," and No. 36, "Fire Brigades."

29. *Danger signs on tanks.* At tanks and at the entrance to all buildings or rooms where explosive substances are stored, used, or generated, danger signs should be posted, telling of the hazard, warning against the carrying of matches or open lights, and prohibiting the entrance of unauthorized persons. (See American Standard Safety Specifications for Industrial Accident Prevention Signs Z-35.1.)

30. *Friction sparks.* Some tests have indicated that friction sparks such as might be produced by striking two ordinary pieces of steel together, do not ignite gasoline vapor-air mixtures, but until more conclusive data have been developed regarding the possibility of igniting various vapor-air mixtures from the friction sparks caused by different types of metal, it is desirable to avoid sparks of any kind in locations where combustible vapor-air mixtures are likely to be present. In attempting to avoid friction sparks, care must be exercised not to introduce conditions favorable to static sparks. (See paragraph 32.)

31. In some operations, the danger of sparks can be somewhat decreased by the use of "non-sparking" tools made of a hardened copper alloy, but these must be regularly inspected to make certain that particles of iron or steel are not embedded in the striking surfaces. Also, while sparks will not be produced when particles of the copper alloy tool [illegible] off, they may be created if particles of the metal being struck are [illegible].

32. Static electricity. Static electric discharges [illegible] caused in a number of ways, each of which must be guarded against if fires and explosions are to be prevented in atmospheres contaminated with gas and air or vapor and air mix-

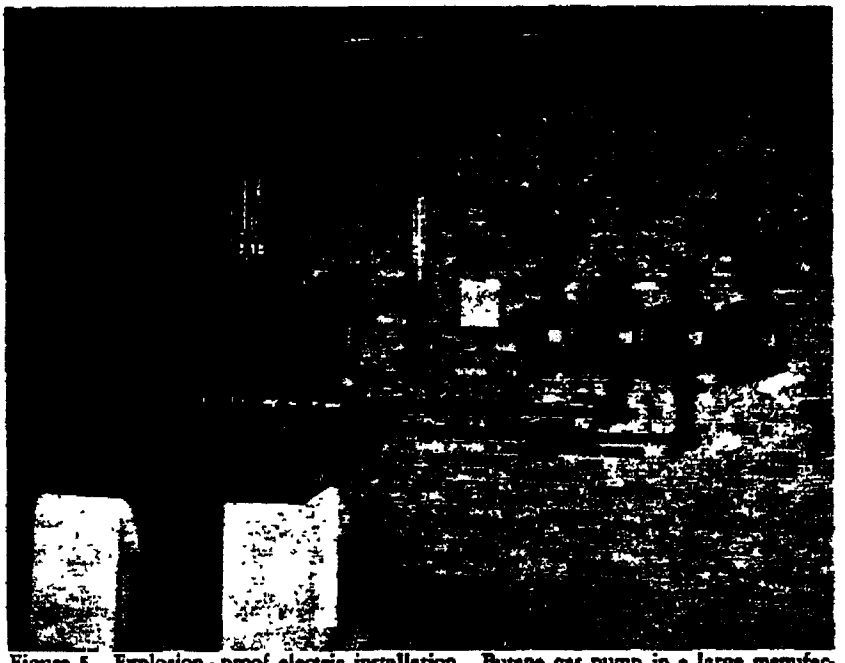


Figure 5. Explosion-proof electric installation. Butane gas pump in a large manufacturing plant. (See paragraph 47.)

tures. Static charges are built up when any two dissimilar surfaces are rubbed together, when two pieces of silk are rubbed; where liquid passes through hose; when liquid is violently agitated in a tank or by belt running over pulleys. This charge as soon as it builds up a sufficiently high potential will discharge to the nearest grounded metal. It is this discharge which is dangerous. (See Safe Practices Pamphlet No. 52, "Static Electricity.")

33. The best precaution against static electricity sparks is to keep all conductors bonded together and grounded. All machines, motors, belts, pipe lines, tanks, or other permanently located metal objects or portable electrical tools or devices should be electrically grounded. In some plants two separate grounds are provided on belts, pulleys or shafts so that in case one should fail the other will prevent building up static charges. These grounds should be checked frequently to make certain that the resistance of the circuit is adequate.

34. In drawing or pouring gasoline from one container to another, it is advisable to keep the two containers in contact with each other or to attach a chain to the pouring container which will maintain this contact. This will prevent the formation of static sparks, and conduct away or equalize any static charge that may otherwise cause ignition of vapor. In making repairs to piping systems, wire jumpers should be used when disconnecting unions and couplings, and when cutting pipe.

35. *Sparks from static charges on belts.* On power transmission belts, static charges may be eliminated by applying belt dressing that has been mixed with aluminum or bronze powder or with a mixture of equal parts of water and glycerine. The surface of the belt will then conduct a static charge and lead it to the earth through a ground wire connected to the shaft bearings or shaft hangers, or to brushes on the metal pulleys over which the belt runs. In many installations, belts can be replaced by spur or metal gears which can be encased and operated in oil. Wherever there is an ignition hazard, both the moving and stationary parts of all machinery should be electrically grounded. (See Safe Practices Pamphlets No. 29, "Electric Equipment in Industrial Plants," and No. 52, "Static Electricity.") (See Figures 3 and 4.)

36. *Stray currents.* Where stray currents may exist, and pipe lines are to be parted, arcing can be prevented by bonding across the proposed gap before the pipe line is parted.

37. *Electric arc.* When practicable, all electric wiring, switches, cut-outs, motors and other electric equipment should be installed outside those rooms where there is an ignition hazard. Electric lamps, for example, may be installed outside such a room so as to throw light through heavy explosion-proof windows. If electrical equipment of any kind must be installed in such rooms, the equipment should be of a type that is inspected and listed by such an organization as Underwriters Laboratories, Inc., and the installation should conform to the requirements of that section of the National Electrical Code relating to Hazardous Locations. Likewise, portable lighting equipment such as handlamps and flash lights should be of approved types.

38. *Heat.* While metals not heated above black heat are generally considered unable to cause direct ignition of a mixture of gas or vapor, there are many vapors such as carbon bisulphide, amylene and many hydrocarbons of the heavy molecule type that are ignited at temperatures below a visible red heat. Also, excessive heat may ignite other substances, and the flame or spark thus produced may ignite an explosive mixture. See the preceding discussion of ignition temperature.

39. *Heating rooms.* Low pressure steam or hot water heat is the one form of safe heating in rooms or buildings where there are certain explosive substances. Low pressure steam is usually available. The pressure in the mains should not exceed 15 lbs. per square inch. There will be a drop in pressure in the feeder pipes so that the pressure at the radiators will be somewhat lower than 15 lbs. per sq. inch. The surface temperature of the radiators will vary therefore from a high of 250.3° F. at 15 lbs. per square inch to 112° F. at atmospheric pressure. *These temperatures should be carefully considered in planning a heating system since carbon disulphide, ether and other volatile solvents may flash on contact with surfaces heated to these temperatures.* The best type of heating system where these chemicals are used is the indirect type, in which air is heated to a predetermined limit and blown into the room. Temperature by this method can be closely controlled. The temperature at any part of the room should never exceed 120° F. In locations where the temperature is likely to reach a dangerous point, recording pyrometers may be used and

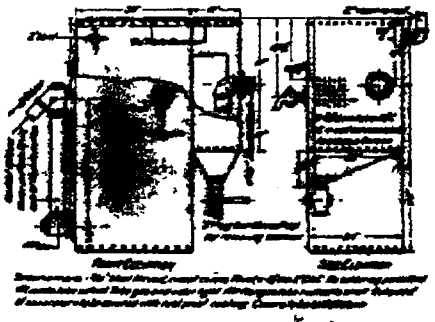
automatic shut-off valves and alarms should be installed. These can be arranged to sound an alarm when the temperature reaches a predetermined limit.

40. *Ignition by overheated bearings.* Overheated bearings can ignite explosive or flammable vapors. Bearings, therefore, should have the best of care, inspection and lubrication. Where roller bearings are not used, it is advisable to install bearings of the self-oiling type. In many plants, automatic alarms are installed to sound if journals or bearings become overheated.

41. *Ignition by belt fires.* Friction of belts is liable to start a fire and thereby ignite an explosive or flammable gas or vapor-air mixture. Belts should not be permitted to rub against each other or against other objects. Neither should they be allowed to slip around pulleys which, because of "freezing," excessive load, or other causes, will not revolve.

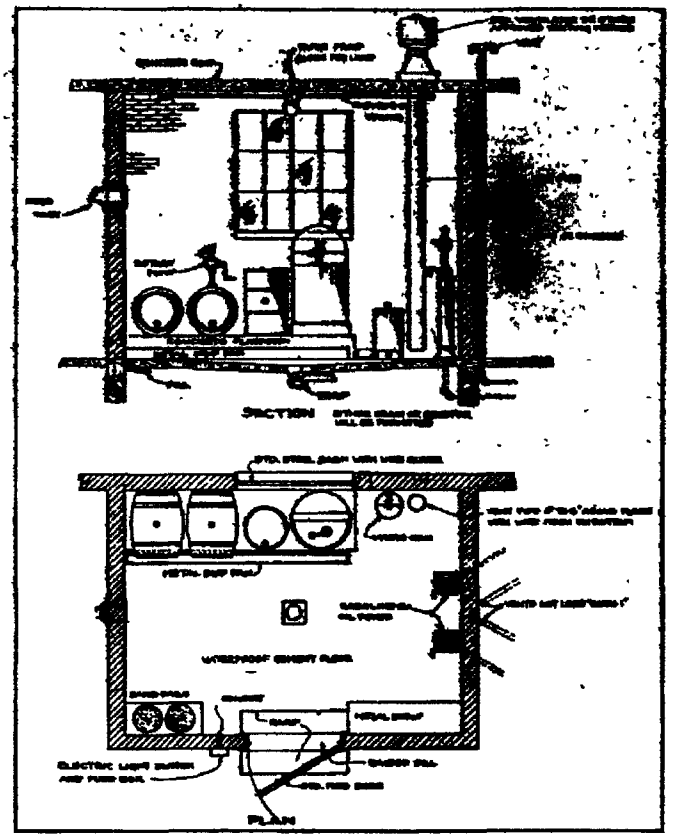
42. *Ignition by the sun and by glass lenses.* Defective window glass, bottles, or other articles of glass through which the sun shines may act as lenses and start a fire. Bottles and other articles should be set out of range of the sun, and the windows can be shaded or painted.

43. *Spontaneous ignition.* The possibilities of spontaneous ignition or decomposition of gases and vapors has been referred to previously. In general, none of the mixtures of common gases or vapors with air will ignite or explode spontaneously. On the other hand, dust accumulations or other substances like rags containing vegetable oils may ignite spontaneously and in turn ignite an explosive or flammable mixture or a flammable liquid that may be present. Spontaneous ignition is the result of a chemical reaction between the oxygen of the air and the material ignited, or bacterial action, or both. As in most chemical reactions, heat is produced. The heat causes the action to become more rapid until the point is reached at which the material bursts into flame; the flame, in turn, may cause an explosion.



Courtesy Crosby-Fiske-Forster "Handbook of Fire Protection"

Figure 6. Oil separator. To be installed in drain so flammable liquids will not flow into sewer. (See paragraph 37.)



Courtesy Crosby-Fiske-Forster "Handbook of Fire Protection"

Figure 7. Well-designed oil house. Walls—brick, stone or concrete; Roof—concrete without exposed metal; Floor—concrete drained to one point, drain to sewer through properly designed trap or oil separator; Door Sill—raised about 6 inches; Door—metal-covered and hung on iron frame; Windows—metal frame and wire glass. Vent pipe extends from floor through roof. (See paragraph 52.)

44. *Ignition by fire-producing chemicals.* Spontaneous ignition, especially in dust and rags containing vegetable oils, has undoubtedly caused some fires and explosions, but many disasters have been attributed to spontaneous ignition when, if the truth were known, they have been caused by a flame, a spark or excessive heat from some other source. Chemicals such as phosphorus, sodium, potassium, pyrophoric nickel and others that catch fire on exposure to air or in contact with moisture, and strong oxidizing agents such as potassium permanganate and nitric acid which will react with organic matter and produce fires, must not be stored near explosive or flammable mixtures such as gases, vapors and liquids.

Preventing Explosive Atmospheres

45. *Tubing and piping.* The use of rubber tubing in place of metal pipe should be prohibited; rubber deteriorates with age, mechanical abrasion, heat, and when in contact with moisture, oil, or acid. Metal piping, or if absolutely necessary, [illegible] flexible tubing, is preferable. Some [illegible] oil and solvent resistant synthetic rubber may be used but [illegible] must be afforded against abrasion, wear and rupture. Gas leakage is [illegible] be avoided. Rigid inspection of gas systems should be instituted and all leaks repaired at once by qualified persons. If the pipe or section to be worked on is not removed or repaired at a distant point

where there is no danger of igniting the gas, great care should be exercised in closing the necessary valves and removing all traces of the gas before starting work. Other points on gases are discussed in Safe Practices Pamphlet No. 31, on "Fire Causes and Prevention."

46. *Acetylene* is discussed in Safe Practices Pamphlets No. 23, on "Gas and Electric Welding," and in No. 95 on "Compressed Gases used in Industry."

47. *Miscellaneous commercial gases.* A number of commercial gases such as propane, butane, blau gas, pintsch gas, and others are used for lighting, welding, and other purposes. These gases should be handled with precautions similar to those observed when handling other combustible gases. (See Figure 5.)

48. *Mechanical rupture.* Compressed and liquefied gases and vapors are used extensively. Great care should be exercised in storing and handling containers for these substances; heat or severe blows may cause them to burst with explosive violence.

49. *Flammable liquids.* Gasoline and other flammable liquids should always be stored in closed containers to prevent undue evaporation and the mixing of their vapors with the air. (See Industrial Safety Series Pamphlet No. Chem-1 "Pipe Lines and Tanks as Causes of Accidents" and Safe Practices Pamphlet No. 63, "Storage Tanks for Oils, Acids and Dry Materials.")

50. *Shipping containers.* In shipping flammable liquids, tank cars, barrels, cans, and other containers should be used in accordance with the regulation of the Bureau of Explosives, 30 Vesey St., New York City. After portable containers are emptied, taps, plugs, and bungs should be tightly replaced immediately. Some users clean out portable containers before returning them to the manufacturers. It should be recognized that a container that is empty with only enough of the volatile flammable liquid remaining to wet the inside may be more dangerous from the standpoint of explosion than the container when filled with liquid, owing to the large volume of explosive mixture that it contains. See Safe Practices Pamphlet No. Pet. 2, "Drums and Barrels." See also Industrial Data Sheets No. D-Chem. 10, "Drums and Other Portable Containers Which Have Held Flammable Substances" and No. D-Pet. 1, "Removing Flammable Vapor from Gasoline Storage Tanks."

51. *Storage tanks.* Large quantities of flammable liquids should be stored in outside tanks preferably below ground and with a barrier to prevent the liquid from flowing into buildings, basements or sewers in event of a leak. The maximum capacities of both underground and above-ground tanks depend upon their proximity to buildings and other tanks. Where explosive mixtures are likely to be present in the tanks, the vent openings should be designed to prevent flame propagation through the vent. Safety diaphragms may also be employed to relieve excess pressure. Local ordinances should be consulted for data on clearances, capacity and construction specifications before work is started on installation of tanks. For details on capacities, material and construction of tanks, foundations, grounding, dikes, vents, pumps, piping, fill pipes, freeing tanks of flammable and explosive vapors, repairs, etc., see Safe Practices Pamphlet No. 63, on "Storage of Flammable Liquids," and Industrial Safety Series Pamphlet No. Chem. 1, "Pipe Lines and Tanks as Causes of Accidents," as well as the Regulations of the National Fire Protection Association.

52. *Oil rooms.* Under certain conditions it may be necessary to provide an oil room inside a building for the storage of limited quantities of flammable liquids. Such oil rooms should have walls, floors, and ceiling made of brick or concrete, 8 inches thick, or of reinforced concrete 4 inches thick. All openings into the room should be provided with automatically closing fire doors; windows should be of wired glass in metallic sash and frames. To prevent the accumulation of vapors in pits and other confined spaces, inside oil rooms should not be below the grade line nor immediately above a cellar or basement. Door openings should have sills raised 6 inches. The floor should be water-proof and this water-proofing extended up the side walls at least 3 inches. Rounded corners that can easily be washed and cleaned should be provided. The floor should pitch to a drain pipe leading outside to a catch basin or terminating at a point where proper precautions have been taken so the surrounding property will not endangered. No drain connections should be made direct to the sewer. Figure 6 shows a well-designed oil separator. It is necessary to clean out an oil separator at regular intervals. If this is not done the separator will become filled and will then discharge its contents into the sewer. In some locations, periodic visits are made by garages to clean out oil separators. (See Figure 7.)

53. *Ventilation.* Proper ventilation should be provided for oil rooms. No system of ventilation is applicable in all cases; the method adopted necessarily varies with the nature of the gas or vapor to be removed and depends upon whether it is heavier or lighter than air. Ventilation may sometimes be secured by arranging screened openings near the floor or near the ceiling or both. It may be necessary to provide a general system of exhaust ventilation by installing fans. In such cases, care must be taken to prevent the exhausted gases or vapors from re-entering the room, or from entering any other place where their presence would be dangerous. Fans should be driven by direct-connected explosion-proof motors or by belt or shafting if the motor is not of the explosion-proof type and is located outside the danger zone. An exhaust system with hoods which trap the gas or vapor at the point of origin is likely to be more satisfactory than general room ventilation. To assist in the solution of ventilation problems, certain gases and vapors are classified as follows:

Lighter than Air	
Acetylene	Pit gas (firedamp)
Carbon Monoxide	Illuminating gas
Hydrogen	

Heavier than Air	
Alcohol	Kerosine
Ether	Illuminating oils
Naphtha	Petroleum
Gasoline	Varnish
Benzol	Amyl acetate
Fuel Oil	Carbon bisulphide

The vapor density of a gas, if standardized against air as 1, may be used to determine its lightness. If its density is less than 1 it is lighter than air, if more than 1 it is heavier. For further details, see Safe Practices Pamphlets No. 32 on "Ventilating Systems" and No. 37 on "Ventilation."

54. *Storage cabinets.* Storage cabinets may be used to keep not more than 50 gallons of flammable liquid, but no other container should hold more than 5 gallons. The cabinet should be made

of at least No. 18 gage sheet iron, with double walls allowing a 1⅛ inch air space. The door should have a three-point lock and be kept closed when not in use. The door sill should be raised at least two inches above the bottom of the cabinet. Some cabinets of this type are vented and where it is practicable they are placed outside the building. (See Fi[illegible]s.)

55. *Portable wheeled tanks and containers.* It may sometimes be necessary to carry flammable liquids in portable containers. Portable wheeled tanks and safety cans have been designed for this purpose. No portable wheeled tank should exceed 60 gallons in capacity. The tank should be of iron or steel, at least 3/16 inch thick, with all openings located at the top. Wheels should be rubber-tired and tanks hung so they are not likely to tip over. Liquids should be drawn from the tank by means of a tight-fitting pump. Whenever practicable, these tanks, when not in use, should be kept outside the building; if they must be within the building, they should not be placed near radiators or other sources of heat. They should be so located that they can be removed quickly in case of fire. A brake and handles at both ends of the tank are desirable

56. *Safety cans.* To minimize the hazard in handling flammable liquids in portable containers in plants, safety cans bearing the label of nationally recognized testing laboratories should be used. This suggestion is not intended to apply to the delivery cans used by oil companies and carried on the side racks of trucks.

57. *Distinguishing colors and labels for containers and piping.* All tanks, cans, and other containers holding flammable liquids should be marked or painted in some distinguishing manner. This should also apply to pipe lines wherever practicable. Serious mistakes might be avoided if, for instance, gasoline containers are painted red, kerosene containers green, etc. All containers not having contents otherwise designated should bear in large letters a description of their contents. The Compressed Gas Manufacturers Association has promulgated a rule that all cylinders of compressed gas be marked, *THIS CYLINDER CONTAINS——* ——." (See Safe Practices Pamphlet No. 88, "Identification of Piping Systems.")

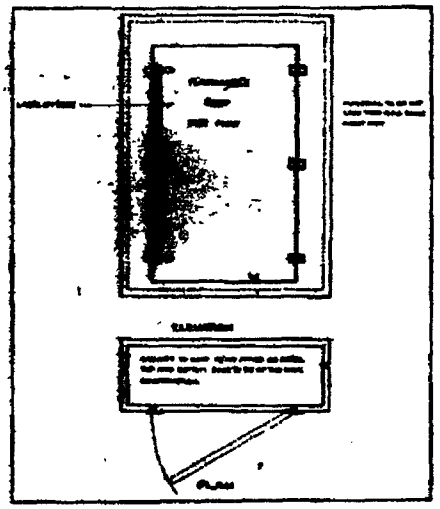
Special Utilization of Volatile Flammable Liquids

58. All rooms or portions of plants in which explosive or flammable gases, vapors, or flammable liquids are used or generated, should comply with the recommendations of the National Fire Protection Association and of local ordinances. In the following sections of this pamphlet, several types of special utilization equipment are discussed and a few safety suggestions applying to each one are presented.

59. *Dip tanks.* The handling of flammable liquids in open containers should be avoided whenever possible. If open vats or tanks must be used, their openings should be as small as possible, and wherever practicable a cover should be provided. Covers may either be hinged or slide on tracks, and should be held open by metal chains of approved type, containing fusible links. All covers should be designed and installed so that they can be closed manually or automatically when released by the action of heat on the fusible links. Covers should be closed when tanks are not in use. If the cover slides on a track, the inclination of the track should not be less than ¾ of an inch per foot. Where steam pipes are used in viscous material, care should be taken that the temperature does not get too high (regulating devices) and that the steam is shut off at the end of the day. (See Safe Practices Pamphlet No. Chem. 5 "Pyroxylin Lacquer Manufacture.")

60. Wherever practicable, ventilation should be by natural means through vents in the building walls at both the ceiling and along the floor. If mechanical ventilation is provided, the installation should conform to the N.F.P.A. Regulations for Blower and Exhaust Systems.

61. Tanks should have an iron or steel overflow pipe leading to a safe place outside the building or to an overflow tank. The pipe should be as straight as possible. This pipe should correspond in diameter to the requirements listed below and should be provided with a coarse strainer at the tank—about ½-inch mesh.



Courtesy National Fire Protection Association

Figure 8. A well-constructed storage cabinet for small quantities of flammable liquids. (See paragraph 54.)

3" pipe for area up to 75 sq ft.
4" pipe for area up to 150 sq. ft.
5" pipe for area up to 225 sq. ft.
6" pipe for area up to 325 sq. ft.

62. Each tank should be provided with a drain pipe, the drain to be equipped with a valve capable of being operated both manually and automatically. The valve openings should be at least 60 per cent larger than the cross-sectional area of the drain pipe.

63. *Japanning and drying ovens.* Drying ovens used for evaporating varnish, japan, and other flammable liquids should have ample provision made for ventilation and explosion venting. If the drying ovens are heated in any way other than by steam there should be a ventilating pipe leading from the heating compartment to a safe point outside the building. This will prevent the collection and possible explosion of the gas or vapor used for heating.

64. *Oil burning equipment.* All equipment used for burning oil should be installed in accordance with the requirements of the National Fire Protection [illegible] Standpipes, accumulators, [illegible]rs, if used, should be [illegible] or equipped with relief valves, [illegible] pipe should be installed on the supply tank; and the system should be so arranged that the oil will return automatically to the supply tank when the pump is shut down.

65. *Cleaning metal parts.* A dangerous practice, rapidly being eliminated

in many garages and other places, involves the use of gasoline in open pans for cleaning grease and oil from metal parts. Alkaline compounds, high flash point solvents (Stoddard solvent or kerosene), carbon tetrachloride mixtures with certain flammable solvents, or trichlorethylene can be used with safety from explosion. Where these substitutes are used, care should be taken to avoid burns from caustic compounds or poisoning from toxic vapors; and, too, accumulation of oil or grease in the cleaning compound should be avoided. For details, see Industrial Data Sheet No. D-Gen. 13 "Removing Oil and Grease from Metal Parts," Safe Practices Pamphlets No. 25, "Acids and Caustics," No. 14, "Goggles" and No. 64, "Respiratory Protective Equipment."

66 *Inert gases.* A practice that has become popular for the prevention of explosions of gases and vapors or fires from flammable liquids, is to keep the amount of oxygen below that which will support combustion. In vessels that are open to the extent of permitting air to enter, the suggested practice is to exclude the air and consequently oxygen by purging or flooding with a gas that will not support combustion.

67. The gases are commonly termed "inert" gases. They may be ordinary compressed carbon dioxide, nitrogen, engine exhaust gas, flue gas or products of combustion from another process; or gas made purposely for purging and flooding by burning gas or oil in what are termed inert gas-making machines. Each situation must be given consideration as to the most economical and satisfactory means of providing the gas; also thought must be given to the use of a gas that will not react with the system or products which it contains. Among the practical situations in which these gases are used are the flooding of vessels in which paint or other combustible material is [illegible]; for pneumatic means of transferring flammable liquids; for flooding storage tanks of volatile flammable liquids, and for purging gas holders or pipelines when taking them out of service for repairs; during repair and for putting them back into service.

68. Inert gases are used not only in normal situations and processes but as a stand-by emergency means for quickly flooding spaces in which an explosive atmosphere or a fire might accidentally occur. As indicated, the objective is to reduce the concentration of oxygen below that which will support a fire or explosion, or in case of a fire to create an atmosphere that will quickly smother it. In addition to diluting and replacing the oxygen, the physical properties of the particular inert substances used have some influence, but the important factor is the reduction in oxygen. In this connection it should be pointed out that an atmosphere that is deficient in amount of oxygen to support an explosion will also be deficient in amount required for life. In all uses of inert gas for prevention of explosions and fires, care must be taken to prevent exposure of persons to the atmosphere unless they have adequate respiratory protection in the form of a U. S. Bureau of Mines approved self-contained oxygen breathing apparatus or a supplied air hose mask.

69. The oxygen deficiency or amount of inert gas in vapor required to prevent explosions varies to some extent with the combustible gases or vapors dealt with. Table 1 and Bureau of Mines Bulletin 279 (1939 edition) give information on this subject.

70. *Flame-suppressing vapors.* Another practice similar to the use of inert gas, is to add to the combustible vapors a non-combustible vapor that dilutes the oxygen. A common example is carbon tetrachloride vapor or certain other halogenated hydrocarbons. These substances may be mixed with the combustible liquid to produce a non-flammable mixture of liquids. Also by using a volatile non-flammable liquid of the proper physical properties it will evaporate with the combustible component and render the resulting vapor-air mixture non-flammable. Another procedure for using these flame-suppressing chemicals is to pour the chemical into the vessel or space which it is desired to render safe from explosion of flammable gases or vapors that might be present as residues. This may also be done in an emergency such as the spillage of a flammable liquid into a utility manhole. The application of these practices requires an understanding of the amount of material and procedures to be followed in particular situations. It must be emphatically pointed out that *most of these materials are very volatile* and can create explosive vapors in a confined space to make the atmosphere dangerous. Carbon tetrachloride, for example, is a toxic substance and men entering areas or vessels where its vapor is present must be supplied with respiratory protective equipment in the form of U. S. Bureau of Mines approved Type B organic vapor masks for low concentrations or fresh air hose masks for concentrations over 2 per cent. Oxygen breathing apparatus (self-contained) may also be used if men are properly trained. More information on this subject can be found in Bureau of Mines Bulletin 279 and in Safe Practices Pamphlet No. Chem. 1, "Pipe Lines and Tanks as Causes of Accidents."

Inspection

71. The large majority of explosions and fires occur in situations where either no hazard was recognized or where it was thought that the hazard was negligible or that it had been taken care of by preventive means. This indicates clearly the need for thorough surveys at regular intervals for the purpose of discovering and eliminating potential explosion hazards. These inspections should be made by qualified persons who, in addition to a knowledge of the dangers of flammable and explosive gases, should have an alert mind to visualize dangerous conditions where none apparently exist at the moment.

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