A. FACTORS AFFECTING THE LIMITS OF FLAMMABILITY

Only a brief discussion of the various factors affecting the limits of flammability will be given. A more complete discussion is given in published reports. The limits are affected by the direction of flame propagation; the shape, diameter, and length of the test apparatus; the temperature and pressure of the mixture at the time of ignition; the percentage of water vapor present; and, indirectly, by the source of ignition.

Wider limits are obtained for upward propagation of flame than for horizontal or downward propagation. Therefore, the risk of an explosion is greater when the mixtures are ignited from below than when ignited from above.

The limits of flammability are widened as the diameter of the apparatus is increased, rapidly at first and then more slowly as the diameter approaches 2 inches. An apparatus greater than 2 inches in diameter gives limits very little different from those obtained with 2-inch apparatus for tests at atmospheric pressure. The apparatus must be long enough to insure continued propagation of flame after the heat imparted to the mixture by the source of ignition has been dissipated. An apparatus 4 feet or more in length is sufficient. It has been found that if the apparatus is closed when the mixtures are ignited and the gases are in gentle turbulence, the lower limit is reduced slightly.[4]

Ordinary variations of laboratory temperatures have no appreciable effect on the limits of flammability. Elevated temperatures cause a widening of the limits. Normal variations of atmospheric pressure have no appreciable effect on the limits. The effect of high pressures on the limits is neither simple nor uniform, but specific for each particular combustible. As yet, no means has been developed for predicting the effect of high pressures on the limits of flammability for any given combustible in air or oxygen. In certain instances both limits are raised, while in others the limits are narrowed. However, increased pressure widens the limits of flammability of saturated hydrocarbons.

The normal quantity of water vapor present in atmospheres at laboratory temperatures affects the lower limit of flammability only to a slight extent. The presence of water vapor reduces the upper limit because some of the oxygen in the mixture is displaced by the water vapor. Since the oxygen concentration is the important factor in an upper-limit mixture, as the oxygen is lowered the amount of combustible that can be burned is decreased, and so the limit is lowered.

[1] H. F. Coward, C. Carpenter, and W. Payman, *J. Chem. Soc.*, **115**, 27 (1919).
[2] H. F. Coward and G. W. Jones, *U. S. Bur. Mines Bull.* No. **503**, 1952.
[3] H. F. Coward, G. W. Jones, C. G. Dunkle, and B. E. Hess, *Mining Met. Invest. Coal Mining Inst. Technol. Co-op. Bull.* No. **30**, 1926.
[4] G. W. Jones, E. S. Harris, and W. E. Miller, *U. S. Bur. Mines Tech. Paper* No. 544, 1933.
[5] G. W. Jones and R. E. Kennedy, *U. S. Bur. Mines Rept. Invest.* No. **3798**, 1945.
[6] G. W. Jones, R. E. Kennedy, and I. Spolan, *U. S. Bur. Mines Rept. Invest.* No. 4554, 1949.

B. LIMITS OF FLAMMABILITY OF GASES AND VAPORS IN AIR

Industrial safety requires that only those values for the limits of flammability of gases and vapors in air be employed that have been obtained in apparatus giving the widest limits. These conditions are met by the apparatus developed by the United States Bureau of Mines and shown in Figure 1. It is specially

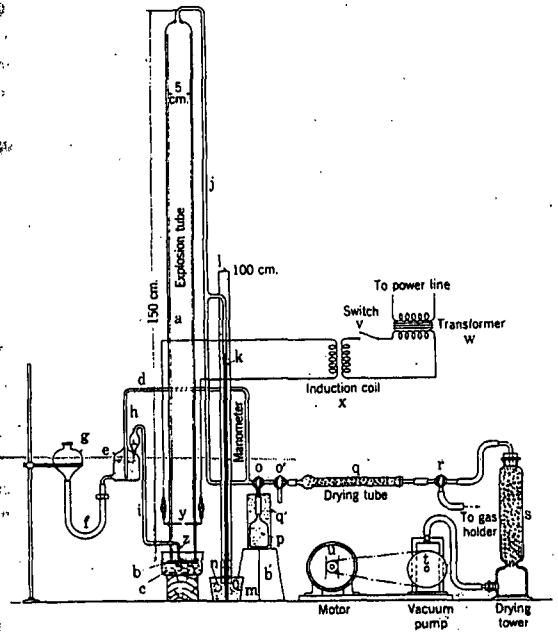

Figure 1. Apparatus for determining the limits of flammability of gases and vapors. (Courtesy Bureau of Mines, U. S. Department of the Interior.)

designed for determining limits of gases, and vapors of liquids that are volatile enough at laboratory temperatures to give flammable mixtures. In Figure 1, *a* is the glass tube in which the mixture is tested. Its lower end is closed by a lightly lubricated ground-glass plate *b* sealed with mercury *c*. It is evacuated by a pump through the tube *j*. The vapor under test is drawn from its liquid in the container *e* in amount measured by the manometer *k*. Air or other "atmosphere" is then admitted through the drying tube *q* until atmospheric pressure is reached. The air and vapor are then thoroughly mixed by circulation, by raising and lowering mercury vessel *g* repeatedly for 10 to 30 minutes, depending upon the density of the added combustible vapor. The mercury seal is then removed, glass plate *b*