has been studied.[23] Possibilities of using several methods of back filling more extensively are presented.

Diesel Exhaust Gases

The effect on quality of tunnel air resulting from the operation of Diesel locomotives is discussed in a report[24] that describes the use of this type of equipment in construction of some of the tunnels of the Delaware Aqueduct in New York State. The selection of Diesel-powered equipment for these operations was based upon apparent advantages in initial cost and in performance on contracts where haulage conditions were adverse.

The first locomotive built for this purpose was factory-tested by the Bureau of Mines to obtain an estimate of the rate of ventilation that would be required when the locomotive was placed in actual service. After this locomotive and others were in use in the tunnels, periodic examination of the tunnel air showed that, under normal operating conditions, the carbon dioxide, carbon monoxide, and oxides of nitrogen content of the air did not exceed limits generally considered permissible in the air of working places, nor was the oxygen content depleted to any significant extent.

These field studies on the use of Diesel engines underground and laboratory experiments showed that the odorous and irritating properties of Diesel exhaust gases are related to the concentration of aldehydes in these gases. In many applications of Diesel engines, it would be desirable to remove aldehydes and eliminate or minimize the odor and irritation. Attempts to do this by scrubbing with water in full-scale laboratory tests showed that only partial removal of aldehydes is obtained under practical operating conditions. Accordingly, the development of an economical method for complete removal of aldehydes from Diesel exhaust gas was undertaken.

A survey of the literature disclosed that the reaction $Na_2SO_3 + HCHO + H_2O \longrightarrow NaOH + CH_2 (NaSO_3) OH$ might be utilized in removing aldehydes from Diesel exhaust gas. The applicability of this reaction to the problem was studied in a series of bench-scale experiments in which air containing approximately 50 ppm of formaldehyde was scrubbed with aqueous solutions of sodium sulfite. These tests showed that substantially complete removal of aldehydes was obtained for comparatively long periods at temperatures up to 140° F. and with solutions containing 2 to 5 percent sodium sulfite. These tests showed also that the removal of formaldehyde decreased markedly when most of the sodium sulfite had been oxidized to sodium sulfate. Since oxidation will occur under practical exhaust-gas scrubbing conditions, it is necessary to inhibit oxidation of sodium sulfite to obtain effective aldehyde

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23/ Ash, S. H., and Westfield, James, Back-Filling Problem in the Anthracite Region as It Relates to Conservation of Anthracite and Prevention of Subsidence: Bureau of Mines Inf. Circ. 7342, 1946, 18 pp.

24/ Berger, L. B., Elliott, M. A., Holtz, J. C., and Schrenk, H. H., Diesel Engines Underground. VI. Use of Diesel Locomotives in Construction of the Delaware Aqueduct; Effect of Exhaust Gases Upon Quality of Tunnel Air: Bureau of Mines Rept. of Investigations 4032, 1947, 26 pp.

removal for extented periods. Previous work outside the Bureau of Mines[25] had shown that hydroquinone was the most effective inhibitor for the oxidation of sodium sulfite. Under the conditions of the bench-scale tests at 160° F., the addition of 0.3 percent hydroquinone to a 5 percent sodium sulfite solution significantly retarded oxidation. For example, at the end of 5 hours the concentration of sodium sulfite was 3.1 percent without inhibitor and 3.9 percent with inhibitor.

A series of full-scale scrubbing tests was made with a scrubbing solution containing 10 percent sodium sulfite and different concentrations of inhibitor. The scrubber used was very simple and consisted essentially of a perforated pipe submerged in the scrubbing solution. The temperature of the scrubbing solution was about 130° F., and the throughput of exhaust gas at NTP was approximately 3,000 cu. ft./hr. The concentration of aldehydes in the inlet gases ranged from 6 to 60 ppm. The results of these tests are shown in figure 28. It will be observed that with no inhibitor the removal of aldehydes decreased markedly after about 2 hours, whereas, with 0.5 percent hydroquinone inhibitor, removal was satisfactory for 15 hours. From these results, it is apparent that a large fraction of aldehydes can be removed from Diesel exhaust gas for extended periods. In the practical application of this method, the concentration of sodium sulfite and inhibitor will depend on the conditions of operation. The cost of the components of the scrubbing solution is nominal, so that the solution may be discarded when it is spent.

Combustion Performance of Fuels in Diesel Engines

In preparation for work on the performance of different fuels in Diesel engines, a series of tests was made in the CFR Diesel engine to determine the combustion performance of this unit and to assess its utility in combustion studies. The results of some of these tests made at a compression ratio of 15:1 and with injection of a commercial Diesel fuel having a 55 cetane number are shown in figure 29. This figure clearly shows the existence of two types of smoke in the exhaust from Diesel engines: (1) Unburned or partly burned fuel (predominating at low fuel:air ratios); and (2) unburned carbon (predominating at high fuel:air ratios). At the low fuel:air ratios very little fuel is burned, since figure 29 shows very little carbon dioxide and considerable particulate material in the exhaust gas. As the fuel:air ratio increases a point is finally reached (0.02 pound of fuel per pound of air) at which substantially all fuel is burned. The region between 0.01 and 0.02 fuel:air ratio is somewhat analogous to the lower limit of inflammability. At higher fuel:air ratios the tendency to form locally overrich regions increases, and smoke consisting chiefly of unburned carbon increases. The results in figure 29, when compared with similar results for commercial Diesel engines, show that the combustion performance of the CFR Diesel engine is inferior. In spite of this, the CFR engine may have certain advantages in the study of the combustion performance of fuels, because it accentuates faulty performance.

25/ Kia-Khwe, J., and Alyea, H. N., A Comparison of Organic Inhibitors in Chain Reactions: Jour. Am. Chem. Soc., vol. 55, 1933, pp. 575-588.

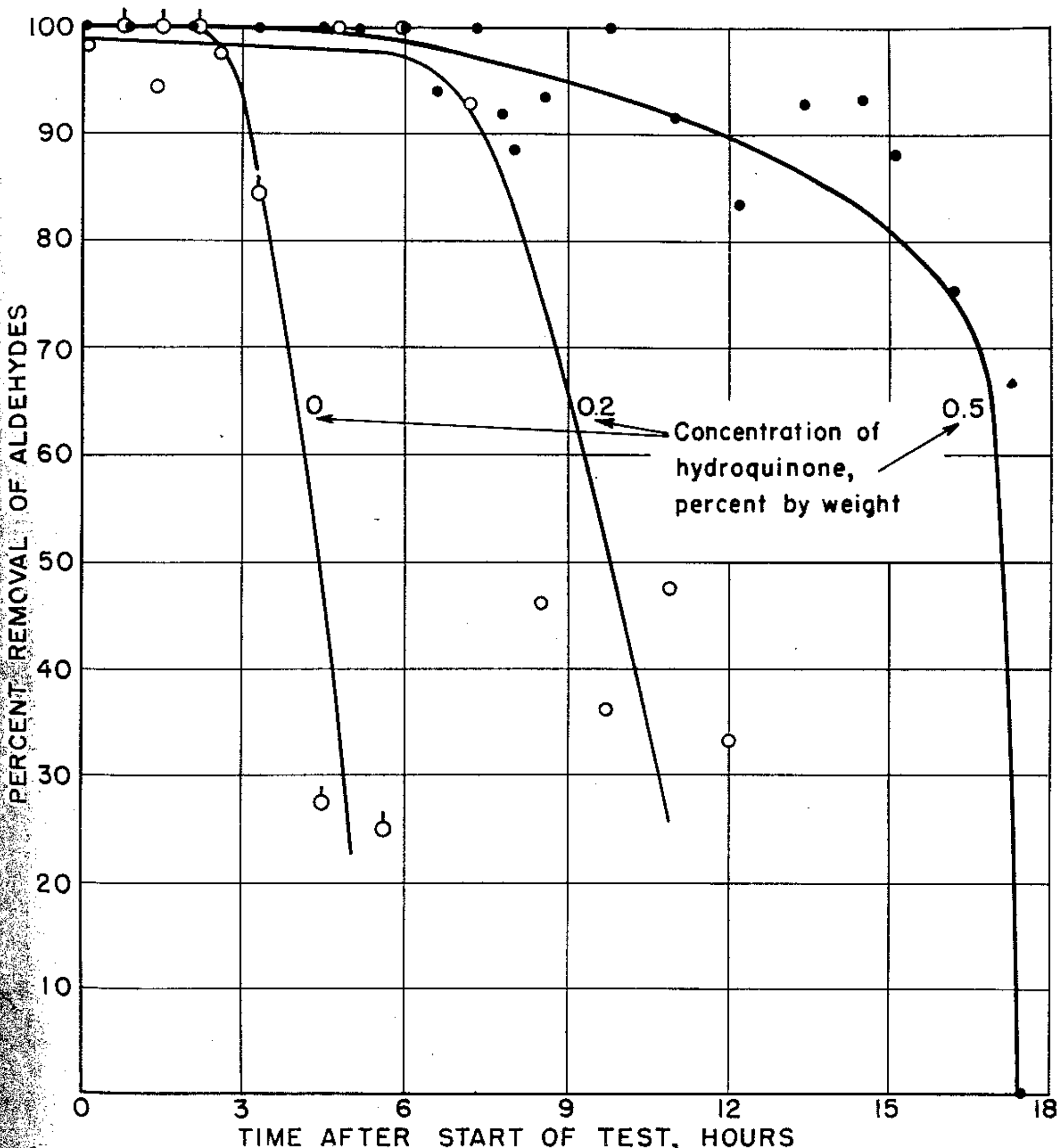

Figure 28. - Effect of inhibitor on removal of aldehydes from Diesel exhaust gas by 10-percent sodium sulfide solutions. (Temperature of scrubber, 133° F.)

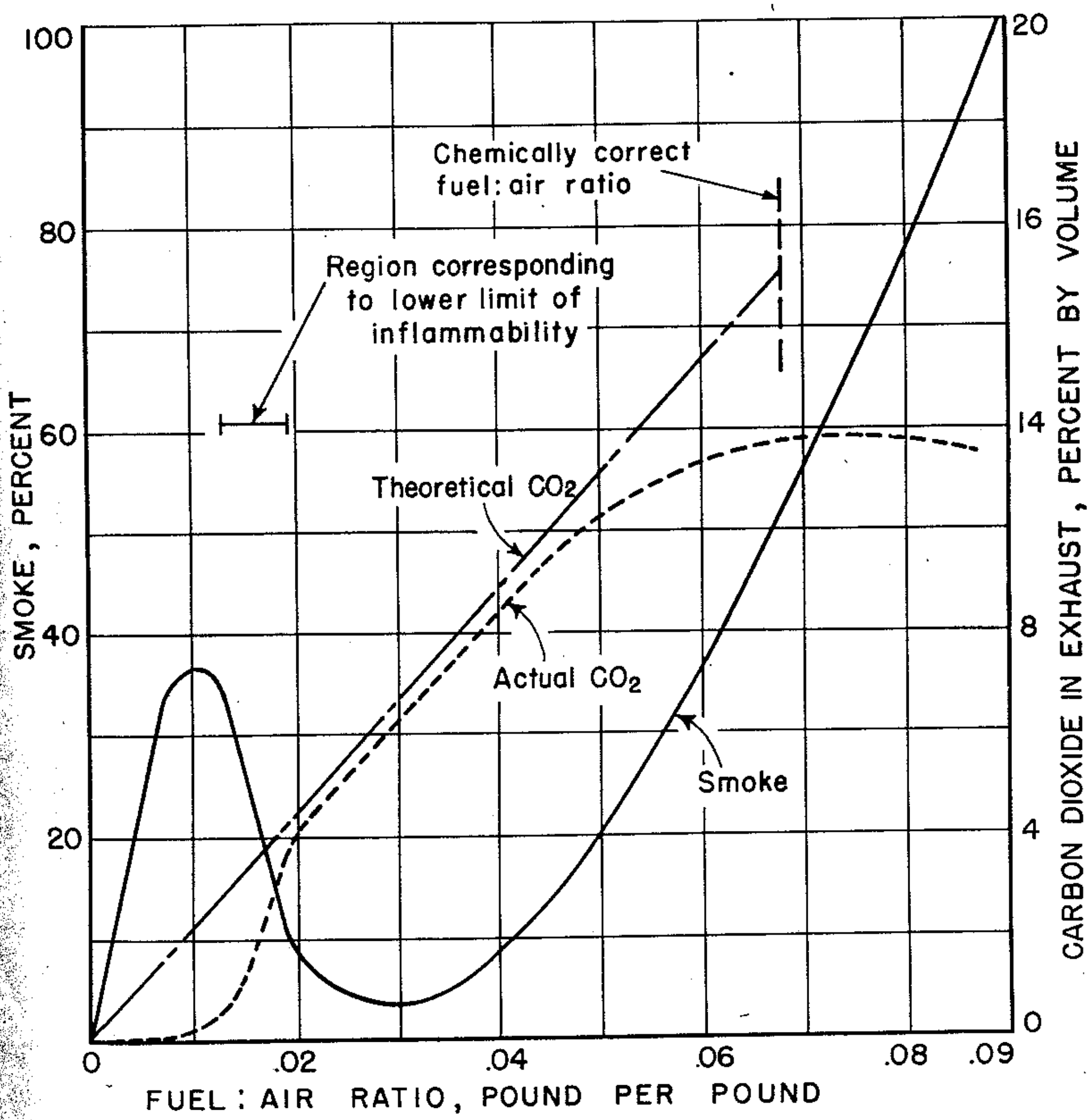

Figure 29. - Effect of fuel:air ratio on carbon dioxide and smoke in exhaust gases from a CFR Diesel engine operated at a compression ratio of 15:1.

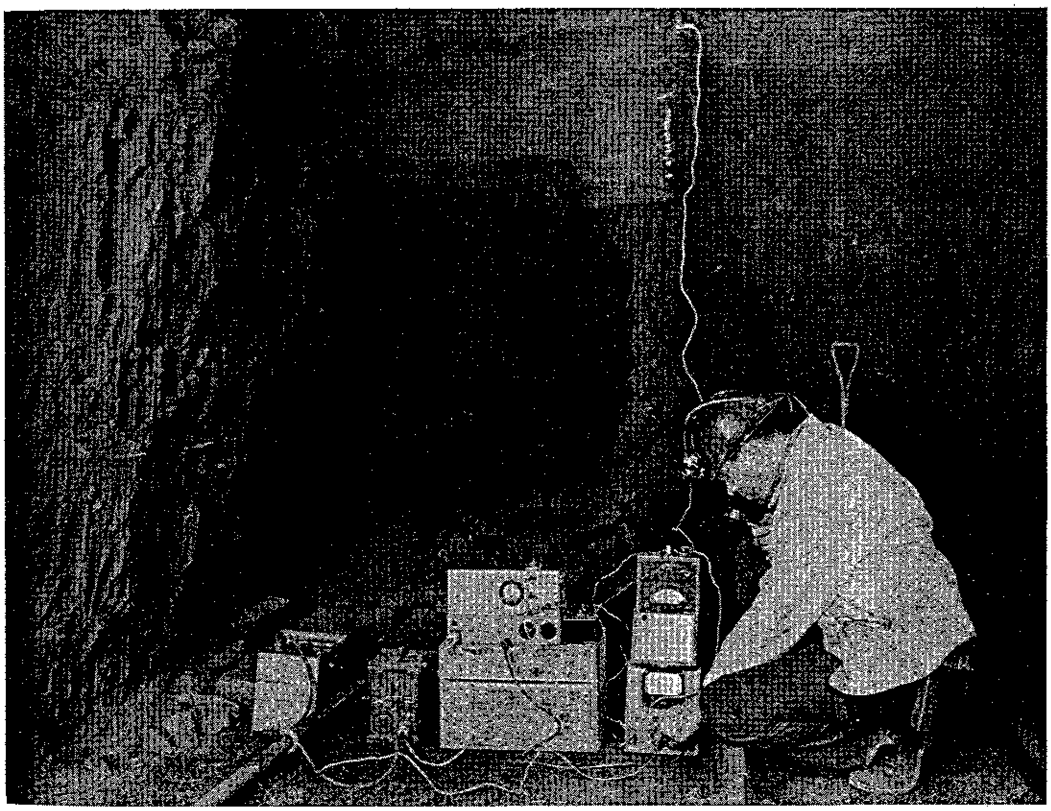

Figure 30. - Experimental apparatus used in developing equipment for 2-way conversation between underground and surface stations.

Electrical Equipment for Mines

From its inception, the Bureau of Mines has investigated electrical devices and machines available to mines for the purpose of encouraging the development and use of equipment that would help to prevent fires, explosions, and shock in coal mines. The investigation of such equipment is conducted at the Central (Pittsburgh, Pa.) Experiment Station by the Electrical-Mechanical Section of the Safety Division in accordance with published regulations termed "schedules." Equipment that passes the prescribed tests and inspections is formally approved and then is designated "permissible" equipment, that is, permissible for use in gassy coal mines. The Federal Mine Safety Code for Bituminous-Coal and Lignite Mines of the United States, effective July 24, 1946, gave permissible equipment substantial recognition as a safety measure, and its use was prescribed under definite conditions. After permissible equipment has been installed in a mine, it is highly important that it be carefully maintained; otherwise, unsafe conditions might develop.26/

Under the eight schedules now in effect, a manufacturer can have nearly every type of equipment used at or near the face of active mine workings investigated for its liability to ignite gas or coal dust or a combination of these. During the fiscal year 1947, 26 approvals were issued. These included 9 loading machines, 7 conveyors, 3 distribution boxes, 2 cutting machines, 1 storage-battery locomotive, 1 mining-machine truck, 1 mine tractor, 1 blower-fan unit, and 1 sound-powered telephone.

Requirements for Multiple-Shot Blasting Units

Although there has been a need for permissible multiple-shot blasting units, only one 10-shot generator unit has been approved to date. This, however, was withdrawn from sale when it proved unsatisfactory in service. To encourage the development and manufacture of satisfactory designs, the permissibility requirements were broadened after a study of experimental models was completed.27/

Mine-Communication Apparatus

Emergency mine-communication apparatus, for use in rescuing trapped man, was further developed and tested under varying conditions in both anthracite and bituminous-coal mines. Figure 30 shows an arrangement of apparatus underground for two-way conversation with a station on the surface. Preliminary experiments indicate that, in addition to its primary objective of emergency service, there is also the definite possibility of enlarging the scope of this apparatus to include daily utility, such as communication from moving cages in shafts and from man-cars on slopes to hoisting engineers, thus contributing to safety as well as efficiency of transportation.

26/ Gleim, E. J., Care and Maintenance of Permissible Electrical Mine Equipment: Trans. 34th Nat. Safety Cong., vol. 1, pt. 1, 1947, pp. 285-289.

27/ Bureau of Mines, Schedule 16B, Multiple-Shot Blasting Units: Approved April 16, 1947, 5 pp. Duplicated from Federal Register, vol. 12, No. 82, Apr. 25, 1947, pp. 2650-2651.

Toxic Mine Atmospheres

In connection with requirements of the Federal Coal Mine Inspection Act, approximately 16,000 gas and dust samples were analyzed, which required more than 110,000 individual determinations. Information was presented on methods for the determination and protection against toxic gases.28/ The significance of Bureau of Mines approval in selection of respiratory protective devices was discussed with emphasis on the selection of the proper device and necessity for proper maintenance.29/

Relationship of Safety and Efficiency in Coal Mining

Accident records have an important bearing on determination of the most effective methods for preventing accidents at coal mines and hence on the cost and rate of production. Analysis and interpretation of statistical data reveal the prevalent types of accidents and their causes, either on a national or a local basis, and provide information necessary for accident-prevention work.30/ Data are given for the number of fatalities in different branches of the mineral industry, and trends of fatality rates are discussed. There has been a definite downward trend in the fatal-injury rate for the period 1931-46 and a very large decrease in fatal injuries for the past 5 years. The rate for 1946 reached an all-time low.

Gaseous Explosions and Use of Explosives

Increase in Charge Limit of Permissible Explosives

Tests to determine the factors that affect the ignition of gas and dust in a coal mine, using larger weights of explosives, were continued during the year.

The principal findings of this year's investigations31/ are summarized as follows.

One hundred and forty tests were made with blown-out, blown-through, and creviced-type shots.

28/ Schrenk, H. H., Methods for Detection and Protection against Toxic Gases: Trans. 21st Ann. Conference and Exhibit, Western Pennsylvania Safety Council and American Society of Safety Engineers, Western Pennsylvania Chapter, Apr. 23-25, 1946, pp. 38-42.

29/ Pearce, S. J., and Schrenk, H. H., Significance of Bureau of Mines Approval in Selection of Respiratory Devices: Safety Eng., vol. 93, No. 1, January 1947, pp. 54-59, inclusive.

30/ Ash, S. H., Safety in Mining: Min. Cong. Jour., February 1947, pp. 35-38.

31/ Hartmann, Irving, and Greenwald, H. P., Tests of Permissible Explosives in the Experimental Coal Mine: Proc. Coal Mine Inst. America, 1946, pp. 68-84.

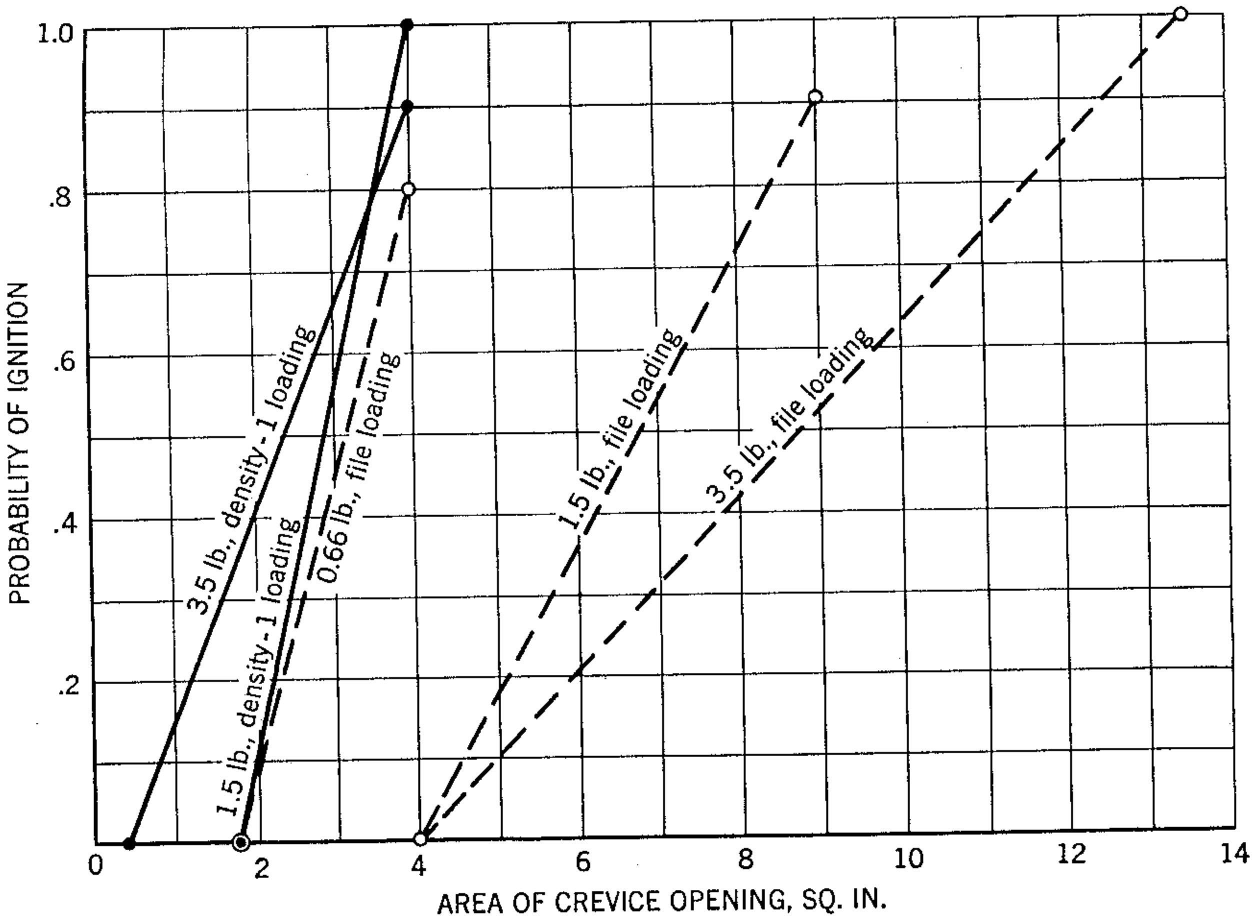

Figure 31. - Effect of weight of explosive and area of crevice opening on probability of gas ignition.

In previous blown-through tests the charge weights ranged from 3.00 to 8.00 pounds. It has been found that, in general, the ignition hazard increases as the charge weight increases. Recent work has shown that in some cases this relationship may not hold. To be certain that smaller weights of explosive would not be more hazardous in blown-through tests, additional work was done this year with weights of 0.50 and 1.50 pounds of the gelatinous explosive, both file-loaded and at density-1 loading, with a 3-inch burden between the shot hole and the free face. No ignitions were obtained in these tests.

In the creviced-type shots, the results showed that conditions governing ignition of gas are more complicated than in blown-out or blown-through shots. The general results are:

1. With creviced shots, file loading is, in general, safer than density-1 loading, but the difference is not as great as in blown-out shots and under some conditions is reversed.

2. Differences in results were found when the crevice opening was opposite, respectively, the front, center, and rear of the explosive, but these differences are no greater than might occur in duplicate tests.

3. It was immaterial whether the crevice opening was circular or rectangular; the cross-sectional area of the opening was the important factor, provided that the vertical dimension of the crevice did not exceed the diameter of the shot hole. In general, the probability of ignition increased with increased area of crevice. If the crevice was cut so that its height was greater than the diameter of the shot hole, the relationship between the area of the crevice and ignition probability no longer held. The ignition hazard of a long, narrow, vertical crevice is less than that of a long, horizontal crevice.

4. Sheathead explosives were found to be safer than unsheathed explosives, but the gain in safety caused by sheathing was less in creviced shots than in blown-out shots.

5. Weight of explosive was an important factor in an unexpected fashion, as will be indicated below.

The data obtained with unsheathed explosives of varying weights are summarized in the following table. The relation of the groups is shown more clearly by figure 31, on which the area of the crevice opening is plotted along the abscissa and probability of ignition along the ordinate. There are solid lines for two weights of explosive loaded density-1 and dashed lines for three weights of explosive file-loaded.

Summary of data on weight of explosive and size of crevice opening

Weight of explosive, lb.	Area of crevice opening, sq. in.	Result	Ignition probability
		A. Density-1 loading	
1.50	1.8	0 ignition in 5 tests	0.0
1.50	4.0	5 ignitions in 5 tests	1.0
3.50	.4	0 ignition in 5 tests	.0
3.50	1.8	10 ignitions in 35 tests	.3
3.50	4.0	23 ignitions in 25 tests	.9
		B. File loading	
0.66	1.8	0 ignition in 5 tests	0.0
.66	4.0	4 ignitions in 5 tests	.8
.66	9.0	5 ignitions in 5 tests	1.0
1.50	4.0	0 ignition in 5 tests	.0
1.50	9.0	9 ignitions in 10 tests	.9
3.50	4.0	0 ignition in 10 tests	.0
3.50	9.0	10 ignitions in 35 tests	.3
3.50	13.5	5 ignitions in 5 tests	1.0

The evidence is somewhat surprising. For a crevice having an area of 1.8 square inches, the probability of ignition from 1.50 pounds of explosive loaded density-1 is not greater than from two-thirds of a pound file-loaded. With file loading, the probability of ignition was found to decrease as the quantity of explosive increased. The hazards arising from creviced shots are more severe than those accompanying blown-out or blown-through shots.

Permissibility Tests

Chemical and physical tests of explosives are made to determine their characteristics so that they can be used safely in gassy and dusty coal mines. The conditions and requirements governing the making of these tests are set forth in Schedule 1F.32/

Nine samples of explosives were submitted to determine their safety for use in gassy and dusty coal mines. Seven of these passed the required tests, and two others were withdrawn and not tested. No blasting devices were submitted for tests during the fiscal year.

On June 30, 1947, the permissible list contained the names of 186 explosives and 9 blasting devices as compared with 180 explosives and 9 blasting devices on the list as of June 30, 1945. One of the explosives which

32/ Bureau of Mines, Procedure for Testing Explosives (Including Sheathed Explosives) and Blasting Devices for Permissibility and Suitability: Sched. 1F, approved January 20, 1945, 11 pp., with amendments approved Mar. 14 and Aug. 7, 1945, and June 24, 1946.