of aldehydes would require 100 volumes of air per pound of exhaust gas to produce an odorless underground atmosphere. This dilution is considerably greater than that generally necessary for carbon monoxide and oxides of nitrogen. It is not surprising, therefore, that the odor of Diesel exhaust gas can be detected even when ventilation is adequate for the harmful constituents of this exhaust.

From the foregoing, it is evident that water is not a satisfactory scrubbing medium for Diesel exhaust gas, as under some conditions none of the aldehydes are removed, and even under the most favorable conditions the removal was not greater than approximately 80 percent. It appears desirable, therefore, to seek a more efficient means for removing aldehydes.

Studies are in progress on the removal of aldehydes by solutions containing sodium sulfite. Preliminary laboratory tests have shown that sodium sulfite solutions are effective at temperatures as high as 160°F. However, it is necessary to retard the oxidation of sodium sulfite by the addition of an inhibitor. Suitable inhibitors have been found, and full-scale tests are in progress.

Performance of Diesel Engines

In studies of the effect of barometric pressure upon the composition of the exhaust gases produced by Diesel engines, considerable data were obtained incidentally on engine performance. Analysis of these data led to the development of methods for converting measurements of the power output of Diesel engines to standard atmospheric conditions; a problem that has confronted the Diesel-engine industry for many years. The fundamental theory underlying this problem was developed in 1941,14/ and the recent tests of three different, normally aspirated, commercial, four-stroke-cycle Diesel engines at different barometric pressures permitted an extension and experimental verification of this theory.15/

Mine Rescue Telephones

The Bureau has experimented with battery-powered telephonic equipment since 1925 in attempts to develop a safe and dependable method of communicating with rescue crews working in dangerous explosive gases. A system consisting of transmitters, receivers, and 1,000 feet of two-conductor cable has been devised and used successfully in actual rescue and recovery work underground. The assembly consists of two dynamic-type receivers, one worn by a member of the crew and one by an attendant at the fresh-air base, one vibration-powered transmitter, one voice-powered transmitter, 1,200 feet of

14/ Elliott, Martin A., A Rational Basis for Correlating Data on Compression-Ignition Engine Performance Obtained at Different Intake and Exhaust Conditions: S.A.E. Jour., vol. 40, 1941, pp. 532-543.

15/ Elliott, Martin A., Conversion of Measurements of Power Output of Diesel Engines to Standard Atmospheric Conditions: Trans., A.S.M.E., vol. 68, 1946, pp. 525-539.

two-conductor cable, and a reel. The cable is used in place of the rope formerly employed for a signal and life line. The conventional sash-cord type of life line was never satisfactory; frequent failures occurred in transmitting pull or jerk signals owing to fouling of the rope or its elasticity. The greater ease and scope of telephone-voice communication removes much of the difficulty and uncertainty formerly experienced and allows the work to be done more safely and efficiently.[16]

Allaying Mine Dust

Coal dust presents an ever-present coal-mine explosion hazard, and persons forced to breath large quantities of it may be made subject to respiratory infection. Dust-allaying equipment for applying water or wetting solutions on the cutter bars of mining machines, on mobile loaders, on belts or conveyors, and on loaded cars is being installed in more mines every year. These installations are far from being standardized, and, to assist in the adoption of the best-known present practices, the Bureau has surveyed available equipment and the installations and systems now in use.[17] A report has been published giving in detail suggested arrangements of dust-allaying equipment as an aid to both manufacturers and mine officials toward obtaining the most efficient systems.

Hazards of Trolley-Locomotive Haulage

Trolley-locomotive haulage has been an important factor in the superior efficiency of production in the underground coal mines of the United States. It has proved to be rapid, economical, and efficient; nevertheless, so many hazardous features and unsafe conditions are involved as to justify the view that the system should be scrapped unless operation can be modified to bring about safe conditions. The hazards have been recognized for years, and although efforts have been made to combat them, the size of equipment and extent of mechanization has increased without finding workable means of safeguarding lives and property against dangers of shock, gas ignitions, and fires. Alternative methods of transportation are being investigated as a solution to the problem in the event that trolley systems cannot be properly safeguarded.[18] Among the methods under study by engineers of the Health and Safety Branch are storage-battery locomotives, conveyor systems, and Diesel locomotives.

16/ Forbes, J. J., Griffith, F. E., Cash, F. E., and Petersen, Max S., Mine Rescue Life-Line Telephone Assemblies: Bureau of Mines Rept. of Investigations 3875, 1946, 9 pp.

17/ Owings, C. W., Suggested Methods for Installing Dust-Allaying Equipment in Bituminous-Coal Mines: Bureau of Mines Rept. of Investigations 3843, 1945, 31 pp.

18/ Harrington, D., and Warncke, R. G., Hazards of the Trolley-Locomotive Haulage Systems: Bureau of Mines Inf. Circ. 7328, 1945, 37 pp.

Diesel Locomotive Tests

Technicians and engineers of the Health and Safety Branch have investigated the use of Diesel locomotives in mines and tunnels to discover their limitations or advantages. One series of tests, on which a report has been published,[19] was conducted by the Bureau of Mines on the Cascade Tunnel of the Great Northern Railway to determine the effects upon the tunnel atmosphere of a Diesel freight engine. The tunnel was not provided with mechanical ventilation. The observed concentrations of carbon dioxide were not hazardous, nor was the oxygen content of the tunnel air depleted to a significant degree. Carbon monoxide was only slightly about 0.01 percent at any time. Oxides of nitrogen were found in a considerable area behind the train in concentrations exceeding 25 parts per million, usually considered the maximum permissible in working places; persons at work in the tunnel might be affected, but crews on moving trains would not be endangered. The foregoing contaminations were observed for trains pulling upgrade; no appreciable contaminations were observed for downgrade trips. Smoke from the locomotive reduced visibility in the tunnel.

Liquefied Natural-Gas Fire in Ohio

On October 20, 1944, a disastrous fire occurred at the liquefaction, storage, and regasification plant of the East Ohio Gas Co., Cleveland, Ohio,[20] as the result of failure of an insulated cylindrical tank in which liquefied natural gas was stored at less than 5 pounds per square inch pressure and at a temperature of minus 250°F. Eye witnesses of the failure of the tank reported that streams of liquid or fog issued from its side, and that almost immediately the tank opened and discharged its entire contents over the plant and adjoining property at a lower elevation. The gas entered storm sewers, was ignited, and exploded. Heavy loss of life and property resulted. The Bureau investigated the disaster to obtain technical information that might help to prevent similar occurrences; representatives of the Health and Safety Branch joined with members of the Fuels and Explosives Branch in the investigation and in the report issued in 1946. Definite conclusions were not reached regarding the cause of the disaster; however, it was determined that the possible causes of failure of the tank were improper design, use of steel unsuited to pressure and temperature conditions in such a tank, or a flaw in the plates or on the welding.

Procedure for Testing Self-Contained Breathing Apparatus

Development of new types of self-contained oxygen or compressed-air breathing apparatus made advisable the revision of the specifications under

19/ Berger, L. B., and McGuire, L. H., Observations on the Use of a Diesel Freight Locomotive through a Railway Tunnel: Bureau of Mines Rept. of Investigations 3887, 1946, 20 pp.

20/ Elliott, M. A., Seibel, C. W., Brown, F. W., Artz, R. T., and Berger, L. B., Report on the Investigation of the Fire at the Liquefaction, Storage, and Regasification Plant of the East Ohio Gas Co., Cleveland, Ohio, Oct. 20, 1944: Bureau of Mines Rept. of Investigations 3867, 1946, 44 pp.

which the Bureau tests such equipment for approval for use in irrespirable and poisonous gases. Tests were made of recently developed types operating by use of oxygen-generating chemical charges, by compressed-air supplies, and by compressed oxygen. Suitable tests and standards of performance were established which all types of apparatus must meet for approval, and a revised schedule was published.21/

Single-Shot Blasting Units

The arrangements and specifications under which tests are made for Bureau approval of blasting units used in gassy mines undergo modification as new devices, and blasting practices are developed. A revised schedule 22/ for testing and approving single-shot units was published.

Coal-Mine Health Hazards

Laboratory and field investigations of health conditions in anthracite and bituminous-coal mines were carried out in connection with requirements of the Federal Coal Mine Inspection Act by Health Division personnel. Dust and gas samples were collected and analyzed.

Petrographic examinations and qualitative and quantitative X-ray diffraction determinations were made on gross samples of rock, coal, traction material, and rock-dusting material in bituminous coal mines. Surveys were made of unhygienic atmospheres in anthracite mines. The drilling speed and dust dissemination of electric-auger, pneumatic rotary, and pneumatic piston drills using different types of drill steel and bits were studied.

Coal mine inspectors and Safety Division personnel were trained in determination of unhygienic dust in coal mines. The course included sources, formation, properties, dissemination, and behavior of dusts; methods of sampling, determining composition and concentration of dust in air, and counting dust particles; physiological effects of exposure to dusts and permissible limits, and principles used in controlling dust.

A report was prepared23/ describing the cells or containers used to hold a known small depth of the dust-containing liquid from impinger, filter paper, and other samples collected from the air while the particles revealed by a microscope are counted to obtain an index of the concentration of dust in the sampled air. Information is given on such subjects as the kinds of cells available, kinds used, actual depths of cells, and construction of single, inexpensive cells.

21/ Procedure for Testing Self-Contained Breathing Apparatus for Permissibility: Bureau of Mines Schedule 13C, 1946; Federal Register July 17, 1946, vol. 11, No. 138.

22/ Bureau of Mines, Single-Shot Blasting Units: Schedule 12D, 1945; Federal Register, Dec. 11, 1945, vol. 10, No. 241.

23/ Brown, C. E., Beatty, R. L., and Kirby, T. B., Dust-Counting Cells: Bureau of Mines Inf. Circ. 7331, 1945, 9 pp.

A study[24] was made to obtain information on the approximate size of the smallest dust particles revealed by or the limit of visibility of various microscopic systems. The information was desired mainly for use in interpreting and evaluating results of number-concentration and particle-size determinations on samples of unhygienic particulate matter collected from industrial atmospheres and in developing better methods for such determinations.

A series of tests[25] was made with a Traube's stalagmometer for thin liquids to see if it could be used for determining the concentration of wetting agent in solution as it came from the nozzle of the water spray used in dust-control work. This determination is important, as under similar conditions and presumably the same concentration of wetting agent in solution it was observed that the effect was not uniform - in some instances the wetting agent added seemed to have no more effect than plain water. This was probably due to improper mixing, which resulted in a concentration lacking in uniformity.

The results indicate that Traube's stalagmometer, which is commercially available, is a device that can be used for accurately determining the concentration of wetting agent in solution. Determinations can be made quickly, on the job, by a person who is not especially trained in laboratory technique. The instrument should find wide application in industry to help interpret results and control concentration wherever a wetting agent is used in a water solution.

Use of Explosives and Gaseous Explosions

Increase in Charge Limit of Permissible Explosives

At the request of the coal-mining industry seeking means of increasing coal production, the Bureau of Mines undertook an investigation to establish whether larger charges than the existing limit of 1.5 pounds of permissible explosives could be used with safety. Since then a continuing study has been conducted in the Experimental Coal Mine to determine the factors that affect the ignition of gas and dust in a coal mine using larger weights of explosives. By 1945 the results were so encouraging that tentative safe conditions were established under which permissible explosives may be used in quantities up to 3 pounds per shot. These were set forth in a new permissible schedule.[26] The tentative approval to raise the limiting charge

---

24/ Brown, C. E., and Feicht, F. L., Size of Smallest Dust Particles Revealed by Various Microscopic Systems: Bureau of Mines Rept. of Investigations 3821, 1945, 11 pp.

25/ Harmon, J. P., Wetting-Agent Concentration in Water Solution Determined by the Drop-Number Method: Bureau of Mines Inf. Circ. 7351, 1946, 6 pp.

26/ Bureau of Mines, Procedure for Testing Explosives (Including Sheathed Explosives) and Blasting Devices for Permissibility and Suitability: Schedule 1F, Approved January 20 and March 14, 1945, 15 pp.; Duplicated from Federal Register, vol. 10, No. 26, Feb. 6, 1945, pp. 1476-1483; No. 60, March 24, 1945, p. 3131.

of permissible explosive per shot hole from 1.5 to 3 pounds has been extended to December 31, 1947. Before making this approval permanent, it is desirable to acquire more knowledge of all the factors that affect the ignition of gas-air mixtures at the coal face by the flame or by the products of detonation of explosives.

To this end, 125 further tests were made in the Experimental Coal Mine with a high-rate gelatin-type permissible explosive. The explosive cartridges used were 1-1/2 inches in diameter and 8 inches long. They were loaded to the rear of boreholes of 2-1/4-inch diameter and fired by a No. 6 detonator at the rear of the charge. Under each set of test conditions, five successive tests were made to determine the probability of ignition of the gas mixture near the test face. Two principal series of tests were made. In one series, termed blow-out shots, the explosive was file-loaded; i.e., the cartridges were laid end to end in the borehole, which was not stemmed. In this case the flame and products of the detonation were ejected chiefly along the borehole. One of the objectives of these tests was to determine the effectiveness of sheathing upon the explosive cartridges. The sheath is 1/4 inch thick and covers the full length but not the ends of the cartridge; its purpose is to cool the flame and combustion products. The tests revealed that in a 36 inch-long borehole the maximum charge of unsheathed explosive for no gas ignitions in five tests was 1.4 pounds, whereas even 3 pounds of sheathed explosive (maximum weight that could be loaded to collar of borehole) gave no ignitions.

The purpose of the second series of tests was to study the danger involved in shot-firing in coal beds where the boreholes intersect fissures or cracks through which flame from the explosive might reach gas near the coal face. In this work, artificial fissures in the form of circular and rectangular holes were introduced between the borehole (which was stemmed) and a shear cut 6 inches distant from the borehole. The following factors were investigated: (1) Effect of shape and cross-sectional area of fissure; (2) effect of location of fissure in relation to explosive charge in borehole; (3) effect of weight of charge, and (4) effect of sheathing on the probability of gas ignition. It was found that with fissures of 6-inch length there is little difference in the probability of ignition in the presence of round or circular holes and rectangular holes of different shapes but of equal cross-sectional areas. This was true for file-loaded explosives and also for a loading density of one; i.e., when the cartridges were deformed so as to fill the entire cross section of the borehole. Study of the effect of increase in cross-sectional area of fissures disclosed that the probability of ignition of the gas by the explosive increases approximately linearly with increase in fissure area. To investigate the effect of location of the fissure relative to the charge in the borehole, tests were made with a round fissure (1-1/2 inch diameter) intercepting the charge at the base of the detonator, midway in the charge, and at the front of the explosive charge. The results indicate that the ignition probability increases slightly as the intercept of the fissure moves toward the front of the charge.

To determine the effect of weight of explosive charge upon ignition tests were made with fissures of constant shapes and areas. Preliminary data indicate that with file loading and also with density-one loading, change in charge weight from 1-1/2 to 3-1/2 pounds did not increase the probability of ignition. This factor is being studied further.

To test the effectiveness of sheathing upon explosive cartridges fired in boreholes in fissured coal, tests were made with file-loaded charges of 1-1/2 and 3-1/2 pounds in the presence of rectangular fissures. The results indicate that sheathing on cartridges reduces the probability of gas ignition considerably below that of unsheathed explosives, but it does not completely eliminate the hazard. The conclusion reached from the work done thus far with shots fired by permissible explosives in stemmed boreholes in fissured coal is that the presence of cracks of fissures greatly enhances the chance of accidental ignition of gas near the working face.

Effect of Sheaths upon the Gaseous Products from Permissible Explosives

The continuing development of safer explosives for use in mining coal is of great interest to both the manufacturer and the user of permissible explosives. Tests by the Bureau of Mines and by testing stations abroad have shown that the ignition hazard of explosives fired in the presence of gassy atmospheres may be reduced by the use of a sheath. The introduction of sheathed explosives in Belgium in 1914, the adoption of sheaths by Great Britain in 1933 and by Germany in 1938, and the continuing consumption of sheathed explosives attests the importance of sheathed explosives in Europe. Although in this country sheathed explosives are not used widely, interest in them is shown by passage of State laws permitting their use on shift and by patents granted to manufacturers of explosives. The formation of poisonous gases in the detonation of explosives also may present an important hazard if they are produced in sufficient quantity. A recent study of the effects of sheaths upon the production of the poisonous gases, carbon monoxide and nitrogen oxides, and upon the total volume of gaseous products has been published.[27] Some effects of sheaths upon nitrogen and carbon recovery and upon the oxygen condition as determined in the Bichel gage and C-J apparatus are discussed here.

In the Bichel gage, the gases are produced by detonation at low loading densities without stemming. The C-J apparatus permits tamping and the use of stemming, affording a higher degree of confinement.

Nitrogen balances were calculated for the gaseous products from a large number of permissible explosives. The nitrogen recovery, which is the percentage of nitrogen in the original explosive which appears in the gaseous products of detonation, gives some indication of completeness of reaction of the nitrogen-bearing constituents, a low nitrogen recovery being indicative of incomplete reaction. Low nitrogen recovery is often, though not

27/ Fieldner, A. C., and Brewer, R. E., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1945: Bureau of Mines. Inf. Circ. 7352, 1945, 103 pp.

always, associated with high production of oxides of nitrogen. The nitrogen-recovery results (fig. 12) indicate that detonation of unsheathed explosives in the Bichel gage was essentially complete, but that the addition of a sheath often caused marked decrease in nitrogen recovery - as low as 56 percent in one case. In the C-J apparatus, nitrogen recoveries were somewhat lower for unsheathed explosives, but the addition of a sheath did not cause so marked a decrease in nitrogen recovery as occurred in the Bichel gage. In other words, explosives under confinement are not so adversely affected by sheaths as are unconfined explosives.

Carbon balances are indicative of the completeness of reaction of the carbonaceous material for unsheathed explosives. Tests in both the C-J apparatus and Bichel gage indicate essentially complete reaction for the unsheathed explosives tested (fig. 13). With sheathed explosives, carbon recovery may be more than 100 percent, because in the computation of the carbon input it was assumed that only the carbonaceous combustible material of the explosive and the sheath entered into the reaction and that none of the sodium bicarbonate of the sheath was decomposed. Some decomposition of the inorganic material did occur, as shown by the high carbon recoveries in some tests. With sheathed explosive in Bichel-gage tests, the recoveries ranged from 64.6 to 125.5 percent; in the C-J apparatus the recoveries ranged from 79.1 to 121.8 percent. These results indicate that a sheath may cause incomplete reaction of the carbonaceous material.

The oxygen-requirement ratio, which is defined as the ratio of the oxygen required to completely oxidize all the carbon and hydrogen in the gaseous products to the oxygen required to oxidize all the carbon and hydrogen in the original explosive, is also indicative of the completeness of reaction. Incompleteness of reaction or the formation of free carbon is indicated by an oxygen-requirement ratio of less than 100 percent. The oxygen-requirement ratio results are presented in figure 14. These results again indicate that the addition of a sheath may cause incomplete reaction, particularly in the Bichel gage.

Effects of Type of Ammonium Nitrate upon the Gaseous Products from Sheathed Permissible Explosives

Tests were made with two permissible explosives, sheathed and unsheathed, similar in all respects except that one sample contained spray-process ammonium nitrate and the other contained graining-kettle ammonium nitrate, to determine the effect of type of ammonium nitrate upon the production of oxides of nitrogen.

It was found that addition of a sheath caused appreciable increase of oxides of nitrogen with the graining-kettle ammonium nitrate, but no significant increase was produced for the spray-process nitrate.

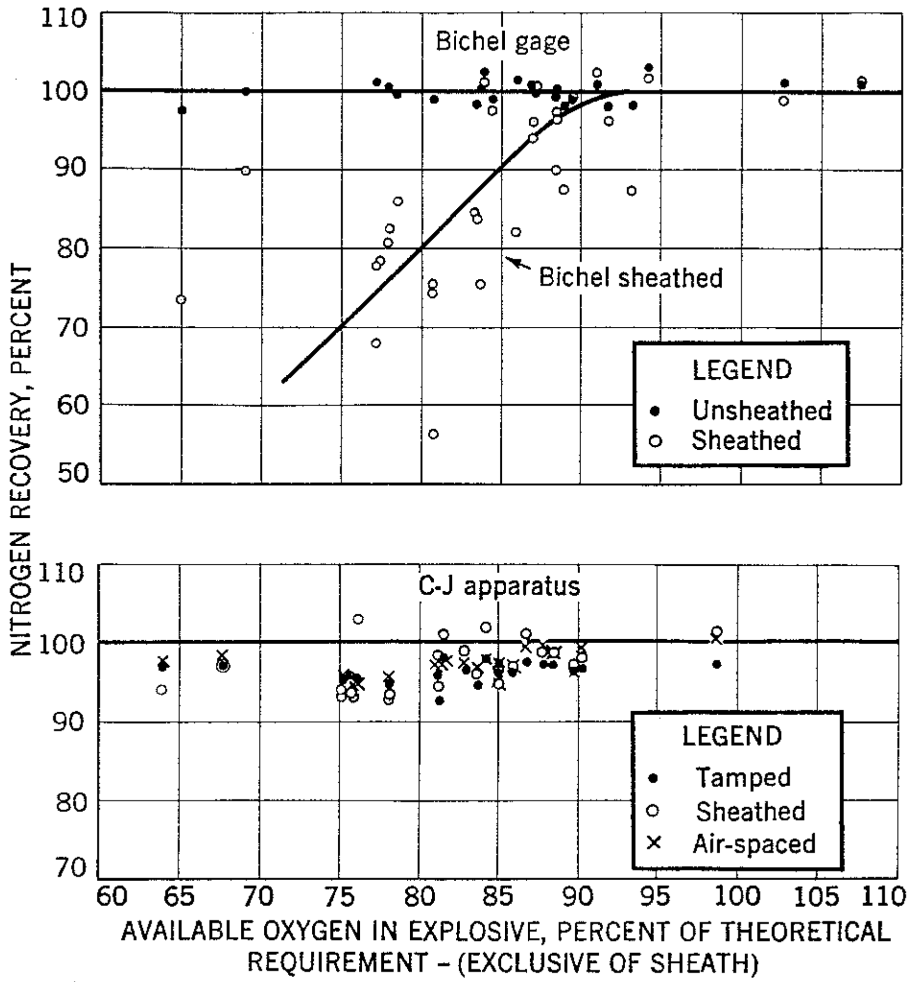

Figure 12. - Nitrogen recovery in Bichel gage and C-J apparatus.

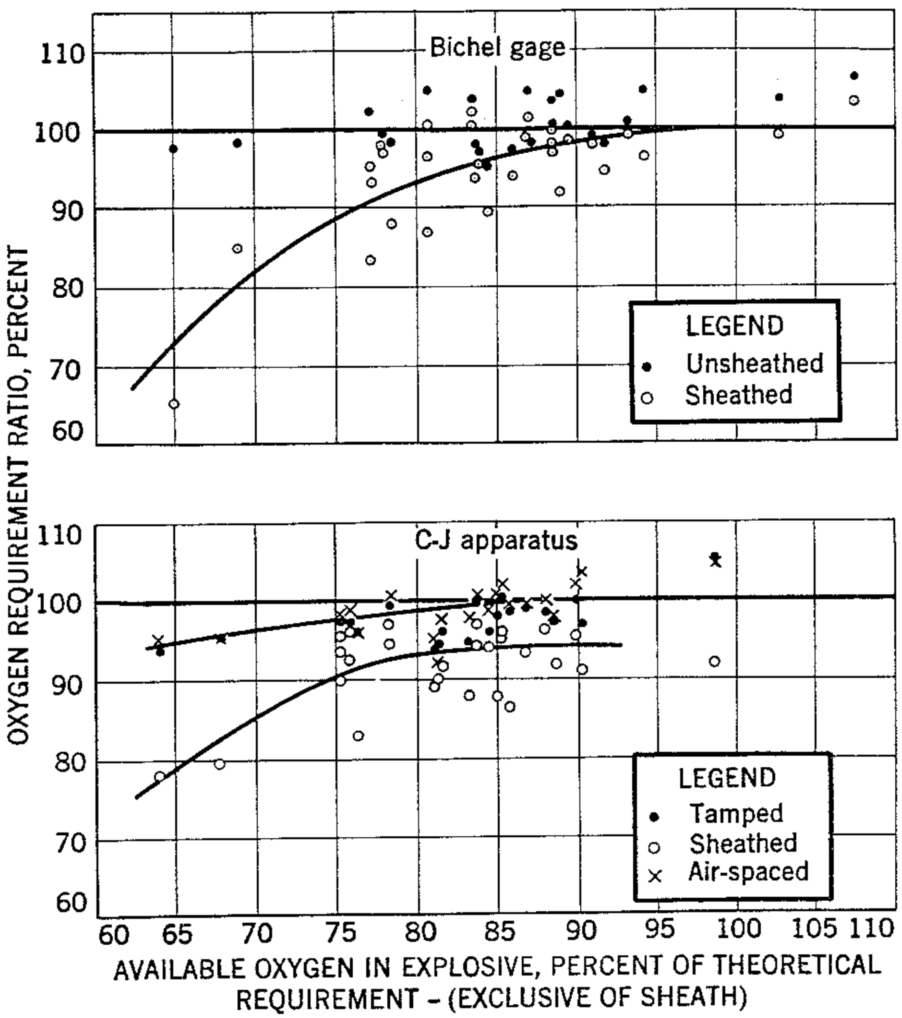

Figure 14. - Incompleteness of reaction as shown by the oxygen requirement ratio.