

MINE GASES AND VENTILATION

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Kirk V. Cammack

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Committee on thesis:

J. F. Macneil

J. P. H. Snitz, Chairman

Representative of English Department:

Richard C. Miller

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CHAPTER I

THE PROBLEM

The mechanization of Indiana coal mines presented many new problems to the production force, the chief problem being the training or education of a personnel for supervisors.

Mechanized mining is yet so new a field that technical men properly trained in the practices of mechanized mining can not be secured as needed, and any attempt to remove trained men from existing organizations and put them in newly mechanized mines is unethical and unlikely to produce satisfactory results.

The best solution, then, is the education of an already existing personnel, accustomed to the problems of the properties in which they are employed, in order that they may become familiar with the scientific developments and principles relative to modern mining.

I. THE PROBLEM

Statement of the problem. While a training program for miners is necessary, the companies have been faced with the problem of securing text material adequate for the needs of the men employed. A rough survey indicated that the average formal education of the men employed as supervisors

was below the ninth-grade level. This would seem to indicate that to attempt to use existing texts covering the fields of chemistry, physics, and engineering, as applied to mine management, would be to insure the failure of any such training program. Accordingly, before a training program designed to meet the needs of the coal mining industry can be inaugurated, it will be necessary:

- (1) To develop a text containing the essential scientific information necessary for modern successful mine management.
- (2) To present these scientific data in a simple and condensed form, limiting their application to problems affecting mine phenomena and expressing them in clear and simple terms so as to be easily understood.
- (3) To prepare this material in such order as would enable a part-time vocational instructor employed (because of state vocational licensing requirements) from the coal mining industry, and without previous teaching experience, to fall naturally into the manner of its presentation and to perform effectively his instructional duties.

II. IMPORTANCE OF THE STUDY

The Indiana coal industry produces annually an average of approximately 18,000,000 tons and has an approximate pay roll of \$25,000,000. The industry is the largest single industrial enterprise in southwestern Indiana. The various companies, having become increasingly aware of the need of a training program, appealed through the State Department of Vocational Education to the Indiana State Teachers College for suitable text material. Involving, as it does, preparation of material to serve as recognized authority for the operating personnel, this study assumes a potential significance greater than is usually attached to such research.

III. PREVIOUS STUDIES RELATIVE TO THE SUBJECT

Singularly enough, considering the needs of the industry, very little attention or study has previously been given to the problem of educating an operating personnel for the mines of Indiana.

In 1933 Mr. Henry Wayne made a study to determine the need for and the possibilities of offering industrial mine education in Terre Haute. He cited the need of "instruction in the kinds of gases found in Indiana mines, methods of dealing with them, proper methods of mine ventilation, administration of first aid, blueprint reading as it is related to Indiana mines, and the state laws regarding

coal mining"; but he offered no material covering these topics.

Mr. C. A. Herbert, Supervising Engineer of the U. S. Bureau of Mines, in 1933, prepared an information circular covering Explosions in Indiana Coal Mines, 1878 to 1933. The purpose of the study was "to provide thorough knowledge of the factors that have led to these past explosions that intelligent steps may be taken to prevent similar occurrences in the future." An extension of this study was made in 1938 by Mr. W. H. Tomlinson for a similar purpose;¹ but both these studies proved too statistical and technical in nature to be used as text material.

The Indiana Coal Mining Institute has published annually, since 1933, copies of its proceedings, but these papers presented as addresses do not contain the background required for instructional classroom material.

IV. ORGANIZATION OF MATERIAL

Before any attempt was made to prepare text material, it was first necessary to determine exactly what technical knowledge was needed in the modern operation of a mine. To determine this in a reliable manner and in a way that would be in no way influenced by individual beliefs or

¹ W. H. Tomlinson, Fatalities in Indiana Coal Mines 1934-38, Washington Bureau of Mines.

past experience of the writer, questionnaires were employed. These questionnaires were submitted to two hundred fifty miners collected in class meetings in the fall of 1938 and similar questionnaires were submitted to the members of the Indiana Coal Mining Institute in 1939. A form of the following questionnaire was used.

Questionnaire to Develop Topics to be Taught in
Evening Extension Classes for Coal Miners

1. Do you believe that instruction through evening extension classes in related technical material would be of value to men employed in Indiana coal mines?
Yes No
2. Do miners and foremen employed in coal mines need instruction in related and technical subjects?
Yes No
3. Would instruction by a qualified person in evening classes meeting once or twice a week meet this need?
Yes No
4. Do you know of satisfactory texts specifically adapted to Indiana problems?
Yes No
If so, name them and give any comment you care to make.

In which of the following topics should the miner and foreman receive instruction? Check them.

1. General chemistry.
2. Chemistry of gases found in coal mines.
3. Composition of air.
4. General physics.
5. Physics of mine gases.
6. Methods of chemical analysis.
7. Determination of content of air through chemical analysis.
8. Physiological effects of the presence of gases commonly found in mine air.
9. Means by which noxious gases are produced.
10. Methods by which the presence of noxious gases are detected.
11. Use of safety lamps.
12. Use of methane detector.
13. Use of Orsat apparatus.
14. Use of hoolamite detector.
15. Method of collecting air samples.
16. Chemical determination of percentage of gas present.
17. Use of barometer.
18. Use of thermometer.
19. Use of water gauge.
20. Use of anemometer.
21. Use of hygrometer.
22. Use of impinger.
23. Methods of dust calculation.

24. Methods of ventilation.
25. Theoretical calculation of fan efficiency.
26. Methods of establishing fan design.
27. Mensuration.
28. Square root.
29. Cube root.
30. Methods of mine ventilation.
31. Physical laws governing mine ventilation.
32. Calculation of quantities.
33. Calculation of air velocities.
34. Calculation of pressures.
35. Calculation of horse power.
36. Calculation of free splits.
37. Calculation of forced splits.
38. Calculation involving choice of design.
39. Calculation involving friction and rubbing surface.
40. Calculation involving variable speeds.
41. Methods of coursing air.
42. Instruction in the construction of stopping and doors.
43. Methods of constructing overcasts.
44. Methods of constructing undercasts.
45. Methods of constructing regulators.
46. Methods of using booster fans.
47. Selection of size of shaft.

48. Selection of size of air course.
49. Construction of rock dust barriers.
50. Instruction in reading electrical prints.
51. Instruction in reading mechanical blueprints.
52. Instruction in reading mine maps.
53. Mine fires.
54. Mine explosions.
55. Use of explosives.
56. Use of cards.
57. Use of compressed air in shooting.
58. Calculating movements of compressed air.
59. Study of Indiana state laws.
60. Study of state laws of principal coal-producing states.
61. Study of federal and state laws concerning oil wells, gravel pits, and coal mines.

List any other topics you believe should be taught.

1. _____
2. _____
3. _____
4. _____
5. _____

Two hundred and five returns were received from miners and sixty-three from mine bosses. All topics were rejected

that did not show either the interest of forty per cent of the total returned questionnaires or seventy per cent of the interest of one of the two groups, as it was believed that topics that did not interest forty per cent of the men in the entire group were not of pertinent interest unless seventy per cent of the men in either group considered above manifested an interest in the subject.

In the final summation of the questionnaires, it was found that selections and rejections ran closer to eighty per cent selection or eighty per cent rejection, excepting the topics covering theoretical calculations of air movement, where eighty-two per cent of the foremen expressed their interest in this subject in contrast to twenty-four per cent of the group of miners. Nineteen topics were eliminated by the questionnaires and fourteen new topics or subdivisions of topics listed were added. Table VI shows the exact tabulation of the results of this questionnaire.

V. SOURCE OF MATERIAL

In the preparation of the text material covering the topics selected by the questionnaire, all known available research material printed in the English language was secured pertaining to the topics desired. None of these covered all the topics desired, and practically all were of a too technical nature to be used in a text. After

study of all material available on the topics, a chapter was prepared covering those points essential to the objective of the lesson or chapter, but with only an occasional direct quotation from any text.

The lesson subject of each chapter, the topics to be studied, and the lesson objective have been listed at the beginning of each chapter as a guide to the instructor in lesson preparation.

CHAPTER II

NORMAL AIR

Lesson Subject:

Common terms used in speaking of gases; the gases composing normal air; and the effects of their presence or absence in mine air.

Terms to be Studied:

Mixture, compound, chemical compound, diffusion, diffused, occlusion, specific gravity.

Gases to be Studied:

Normal air, oxygen, nitrogen, carbon dioxide, argon.

Lesson Objective:

To learn: correct use of these terms; the amount of each gas in normal air; its use; effect on air of passage through the mine; method of detecting change; effect on human life.

CHAPTER II

NORMAL AIR

The subject of mine gases is an important one, for every person engaged in mining--miners, fire bosses, foremen, and superintendents--should have a thorough, practical knowledge of the various gases met in coal mine operation. Such a knowledge, properly applied, will greatly lessen the hazard due to their occurrence in mines.

In the study of mine gases the best practice is first to examine the composition of normal air and the nature of the gases composing it. The first step in such a study must be the definition of a few terms which will be used in the discussion of the various gases.

Definition of terms. The first of these are two terms which may well be considered together. These are mechanical mixture and chemical compound. Possibly the best way to understand the meaning of these two terms is by the use of a concrete illustration. For instance, if some sulphur and iron filings were mixed together, the sulphur and pieces of iron (while mixed together) would retain their same form. This mixture would be called a mechanical mixture, as there has been no change save that of mixing. Now, suppose the mixture were heated to a red heat and then allowed to cool.

A great change would have taken place. No sulphur or iron filings could be recognized, but instead an entirely new substance would have been found. Thus, it would be said that the sulphur and iron had united chemically to form a new substance, this substance being a chemical compound of iron and sulphur.

The next term to study is specific gravity. Briefly, the specific gravity of any solid or liquid substance denotes how much lighter or heavier a volume of that substance is than an equal volume of water. So, if it were said the specific gravity of lead was eleven, it would mean that a cubic foot of lead was eleven times heavier than a cubic foot of water.

Similarly, when the specific gravity of a gas is spoken of, it means how much lighter or heavier it is than an equal volume of air at the same pressure and temperature. If it is said that blackdamp has a specific gravity of 1.5, it would mean that it was one and one-half times heavier than air.

The next term to define is diffusion. Diffusion means the gradual mixing or mingling of two or more gases. Thus, if a smudge was placed in the middle of a room in which no air was stirring, the smoke would gradually spread to all parts of the room. This would be diffusion or the

smoke would have been diffused. Once gases are mixed this way, they will not separate or stratify again. This fact is very important, as will be seen later.

The last term is occlusion, which is just another way of saying absorption or absorbed. Thus, when it is said a gas is occluded in the coal, it means that the coal has absorbed the gas and it is held in the coal and in the joints and slips.

If the above four terms are well understood, they will greatly help in the following discussion of normal air and mine air and gases.

Composition of air. Air is a mechanical mixture of oxygen, nitrogen, carbon dioxide, argon, and other rare gases. These are found in the same proportions in the air, no matter in what part of the world the samples are taken. By careful analysis it has been found that these gases occur in air in the following per cent by volume:

Nitrogen	78.09%
Oxygen	20.94%
Carbon dioxide03%
Argon and other gases94%

So, for all practical purposes, it may be said that normal air is seventy-eight per cent nitrogen, twenty-one per cent oxygen, and one per cent of other gases.

Oxygen. Oxygen, being the most important, will be studied first. In order to shorten the work of writing, the symbol O_2 is used to mean oxygen. The following list gives the chief properties of oxygen:

OXYGEN

Chemical symbol O_2	Not poisonous
Specific gravity 1.105	Colorless
Heavier than air	Odorless
Supports combustion	Tasteless
Not combustible	

As mentioned previously, oxygen is the most important gas because it is absolutely necessary to support life and to support combustion. Life cannot exist or combustion or burning take place without oxygen. Oxygen is also necessary for the growth of plants and for the rusting of metals--the oxygen combining with the iron of the metal to form a compound.

In a study of mine air, it is found that normal air will be found at the first of the intake and that the oxygen in the air will become less as the air passes through the mine. One of the reasons for this is that the coal on the ribs and the faces absorbs the oxygen and gives off other gases. Decay or rotting of timber takes oxygen. The breathing of men and animals and the burning of lights also

use oxygen. If an ample current of air is circulated in the mine, the oxygen content of the air will not be seriously lowered; but, if this is not the situation, the oxygen content of the mine air will be lowered and serious results will follow. The effects on a man, on a flame safety lamp, and on a carbide light are shown in Table I.

From Table I it may be seen that the danger may easily be detected by a flame safety lamp or a carbide light. When a carbide light begins to smoke heavily, it is time for workers to get to fresh air.¹

Nitrogen. The next important gas in normal air is nitrogen and the following is a list of its properties:

NITROGEN

Chemical symbol N_2	Not combustible
Specific gravity .967	Not poisonous
Lighter than air	Colorless
Will not support combustion	Odorless
Will not support life	Tasteless

Nitrogen, so far as human life is concerned, has no value or exerts no harmful effect in mine air. It will not burn, is not poisonous, and plays no part in the mine

¹ "Coal Mine Gases," Bulletin 39, Washington, D. C., United States Department of the Interior, 1936.

TABLE I
EFFECTS OF DEFICIENCY OF OXYGEN

Oxygen Present	Effect on Carbide Light	Effect on Man
21%	burns normally	breathes normally
19%	light will smoke, begin to pull away from wick or tube, sputter or flicker	breathes a little more rapidly
16½%	flame safety lamp will go out	breathes faster, heart beats a little faster
15%	carbide light will pull 1/8" away from tube	becomes dizzy, ears buzz, headache, rapid heart beat
12½%	carbide light will be put out	knees weak, may collapse, breathing labored, man's life in great danger

atmosphere, save that it fills up the space not occupied by oxygen or other gases. It should be remembered, though, that nitrogen will not support life and that a man would smother in it if the oxygen were removed.

Argon, being a completely inert gas and having many of the same properties as nitrogen, will not be considered in our study of gas as found in normal air or mine air.

Carbon dioxide. The last gas to study is carbon dioxide, which occurs in very small quantities in normal air. The following list of its properties is given:

CARBON DIOXIDE

Chemical symbol CO_2	Non-combustible
Specific gravity 1.529	Non-poisonous
Heavier than air	Colorless
Has an acid taste	Odorless

This gas occurs as .03 per cent in normal air and is used by some plants in their growth. Its presence in mine air is increased by the breathing of men and animals, the rotting of timbers, the burning of lights or fires, and the fumes from explosives. It occurs occluded in the coal and is given off at the face along with methane. It is found in great quantities after an explosion or mine fire. Mixed with some other gases, it is known as blackdamp and

is dangerous if very much is present. Being heavier than air, it will be found to lie next to the floor, in swamps, and at the faces of working places going down hill. Table II shows its effect on man when occurring as blackdamp.

The occurrence, detection, and effects of this gas will be more thoroughly discussed in the next lesson under the heading, "Blackdamp."

TABLE II

EFFECT OF CONCENTRATIONS OF CARBON DIOXIDE

Per Cent in Air	Effect on Man ²
1%	will breathe more rapidly
2½%	breathing very rapid
5%	breathing very difficult, legs weak
10%	collapse
12%	unconsciousness and probable death

² J. J. Forbes and G. W. Grove, "Mine Gases and Methods for their Detection," Washington, D. C., Superintendent of Documents, 1938.

QUESTIONS FOR CHAPTER II

1. What is meant by specific gravity?
2. What is meant by mechanical mixture?
3. What is meant by chemical mixture?
4. If some sulphur and iron filings were mixed together, would this result in a mechanical or chemical mixture?
5. If the sulphur and iron filings were heated to a red heat, what new substance would be formed?
6. What is meant by occlusion?
7. What is meant by diffusion?
8. Name the various gases of which the air is composed.
9. Name the physical and chemical properties of oxygen.
10. How may the lack of oxygen be detected?
11. State what you would do if you were walking down hill or into old workings in the mine and your light shot out in a long blaze and began to smoke heavily.
12. What would you do in the above case if you were traveling against the air?
13. You are going along an entry in old works with your lamp on your cap or your safety lamp above your head. You lower it knee high--it smokes, sputters, and goes out. What has happened?
14. What per cent of oxygen must be present to support life?

15. How will the lack of oxygen in air influence a man's breathing?
16. How will the lack of oxygen in air influence a man's heart action?
17. Is every headache occurring in the mine due to bad air?
18. What is the specific gravity of oxygen?
19. What is the specific gravity of nitrogen?
20. What gas has no value, as far as human life is concerned, or exerts no harmful effect in mine air?
21. What gas is completely inert?
22. What is the specific gravity of carbon dioxide?
23. Why is it important to know the specific gravity of carbon dioxide?
24. How is carbon dioxide produced in coal mines?
25. Name one of the gases occurring in the fumes of powder.
26. What gases may be taken from the air and what gases may be added to it in the passage through the mine?
27. What per cent of oxygen must be present for a safety lamp to burn?
28. What per cent of oxygen must be present for a carbide light to burn?
29. What per cent of carbon dioxide in the mine air is likely to cause probable death?
30. Where will carbon dioxide most probably be found in

a mine?

31. What more common name is known for the mixture of depleted air and carbon dioxide?

CHAPTER III

MINE GASES

Lesson Subject:

Noxious and explosive mine gases, their properties, occurrence, detection, and prevention.

Mine Gases to be Studied:

Firedamp; blackdamp; whitedamp; flashdamp; stinkdamp; hydrogen; and acetylene.

Lesson Objective:

To learn what these gases are, where they may be expected to be found in the mines, what their effect is on human life, how they may be discovered, how they may be guarded against, how they may be removed, and effect of water vapor.

CHAPTER III

MINE GASES

In the last chapter, gases found in normal air were studied. In that chapter, some terms used in the study of gases were defined, the occurrence and properties of the gases forming normal air were discussed and the effect on normal air by its passage through a mine was considered. In this chapter, the common mine gases will be studied. From the study of these gases, the chief points to be learned are what they are like, how they occur, how they may be detected, and what dangers arise when they occur.

Methane. The first of these and the most common is methane, or as it is more commonly called when mixed with air, firedamp or marsh gas. The following table shows its properties:

METHANE (MARSH GAS)³

Chemical symbol CH ₄	Will burn
It is a chemical compound	Explosive
Will not support combustion	Not poisonous
Specific gravity .559	Colorless
Will not support life	Odorless

³ "Coal Mine Gases," Trade and Industrial. Series No. 9. Bulletin #39. Washington, D. C. Department of Interior, 1931.

Firedamp, the common explosive gas in mines, is a mixture of methane and air and is found in almost all mines at some time or other during their life. This is important to remember, as there have been several mines which had been considered non-gaseous in which gas later has been ignited and severe accidents have resulted.

This gas occurs occluded in the coal and in the faults, slips, and bedding planes of the seam. It escapes from the coal by coming through very small fissures in cracks, called "feeders." As working faces are advanced, fresh feeders are encountered in each fall; consequently, working places in new work will have more gas than old works where the gas has a chance to "bleed" off. A working section "on the move" or "in a squeeze" will also have more gas because of the squeezing and bursting effect on the pillars. Also, some coal seams have methane in the slate above the seam or in the fireclay below the seam, and a squeeze will force out or turn loose this gas. Much methane will also be found in a region of faults, slips, or rolls, as the gas follows these structures through the coal mine seam.

Methane is the only important inflammable gas issuing from coal. A mixture of it and air is explosive and can be ignited when there is five per cent of methane in the air. The maximum explosibility of a methane and air mixture

is reached when the methane present is about nine per cent of the volume. If there is more than fifteen per cent of methane present, the mixture is not explosive and cannot be ignited. Five per cent, the lowest explosive limit, nine per cent the most intense explosive point, and fifteen per cent, the limit beyond which the gas is not explosive, are points that should be remembered.⁴

Methane having a specific gravity of .559 is lighter than air and will accumulate in entries or rooms going up hill, or on top of falls, or in other holes in the roof. It will also accumulate in the face of advance workings and other places where there is not enough air in circulation to dilute or carry it away. Methane once mixed with air below the explosive limit will not again separate or stratify to an extent that it can be ignited.

Methane, being colorless, odorless, and tasteless, cannot be detected by the sight, taste, or smell, although sometimes other gases occurring with it will make its detection possible by one of the senses. The safe method of detection most commonly used is by observing the effect produced on the flame of a safety lamp, for the presence of this gas can be detected on a flame testing lamp by an experienced fire boss when one per cent or more is present.

⁴ Coal Miner's Pocketbook. New York City, New York. McGraw Hill Book Co., p. 850-853.

Its detection by the safety lamp will be studied under the next chapter. It should be noted before leaving this subject that, while methane is not explosive until five per cent is reached, it has been proved conclusively that less than this amount will generate an explosion when mixed with coal dust.⁵ In other words, mixed with very fine coal dust in the air, one per cent of methane may mean an explosive mixture. For this reason, methane on the return should be kept below five-tenths of one per cent, particularly if the return is on the haulage road.

Blackdamp. This gas is a mixture of depleted air and carbon dioxide but is not as commonly found as firedamp. However, it is often found in some mines. It is found at the floor and in swamps, dips, low parts of the mines, in sealed works, and in the return from mine fires. It is produced by any action that removes oxygen and adds carbon dioxide to the air current, as for example, the burning of lamps, breathing of men and animals, burning of mine fires, and by the decaying of timbers, ties, etc. Sometimes, it has been found occluded in the coal seam. While blackdamp is not poisonous, a man will soon be smothered when it is

⁵ George S. Rice and H. P. Greenwald, "Coal Dust Explosibility Factors Indicated by Experimental Mine Investigations," Technical Paper 464, Washington, D. C., United States Government Printing Office, 1929.

present in large quantities thus materially reducing the oxygen content. It is easily detected by use of flame lamps, and may be detected by the difficulty in breathing.

Flashdamp. Another mine gas that should be mentioned at this time is "flashdamp."⁶ This is the name most commonly used by fire bosses. Flashdamp is a mixture of methane, carbon dioxide and nitrogen and is seldom encountered in the mines. Its presence causes a testing lamp to give a peculiar flame which flares up with a characteristic methane cap, only darker, then suddenly going out. Whether it is found near the floor or roof depends upon the percentages in the mixture of methane, carbon dioxide, and nitrogen.

Carbon monoxide. The next gas in importance is carbon monoxide or whitedamp, as it is called by miners when mixed with air, and the following list gives its properties:

CARBON MONOXIDE (WHITEDAMP)

Chemical symbol CO	Will burn
Specific gravity .967	Is explosive
Is a chemical compound	<u>Extremely poisonous</u>
Will not support combustion	Colorless
Will not support life	Odorless

⁶ J. K. Clement, "The Influence of Inert Gases on Inflammable Gaseous Mixtures," Technical Paper 43, Washington, D. C., United States Department of the Interior, 1913.

Carbon monoxide is the product of incomplete combustion--for example, the slow burning of gob fire in depleted air. Considerable carbon monoxide is always found in the return air coming from a mine fire and is also produced to a limited extent in the explosion of powder in blasting. About five and one-half cubic feet of carbon monoxide is generated when one and one-half pounds of black powder is exploded. Although this gas is inflammable and explosive, it is not dangerous from this cause, as it would require twelve and one-half per cent of CO to be present to form an explosive mixture; and such a strong percentage in mine air is practically unknown.

Carbon monoxide is extremely dangerous as a poisonous gas and a percentage as small as two-tenths of one per cent of this gas, if breathed for any length of time, is fatal. The effect is cumulative and will cause permanent injury to the health. It has a poisonous effect, the victim becoming weak, nervous, and helpless. A man inhaling a mixture containing as little as one-tenth of one per cent of this gas for one hour, would be unable to walk. This gas, being lighter than air, will be next to the roof and cannot be detected by a safety lamp; for, although it gives a cap similar to methane, only lighter, before enough of the gas could be present to be detected by lamp, the atmosphere would be fatal to breathe.

Another source of this danger is from the exhaust of gas engines. No form of gas engine as known at present should ever be operated underground; and on top every precaution should be used to operate a car or gas engine in a garage or confined space, as many people have lost their lives in this way. A car running in an ordinary one-car garage for fifteen minutes may create a deadly atmosphere.

Formerly, the ordinary means of testing for this gas was by the use of canaries or mice, but lately a device has been perfected called the hoolamite indicator by which the air can be tested mechanically for the presence of carbon monoxide. This indicator is merely a little glass tube filled with a powdered chemical. When air is drawn through it, if any CO is present, the powder will change color, the degree of change of color depending upon the amount of CO present.

Hydrogen. The gases that have been named are the common mine gases, but three more which sometimes, although very rarely, occur will be given. The first of these is hydrogen and the chart gives its characteristics:

HYDROGEN

Chemical symbol H_2	Is an element
Specific gravity .069	Very explosive
Will not support combustion	Non-poisonous
Will not support life	Colorless

TABLE III

OCCURRENCE AND EFFECT OF COMMON MINE GASES

Name	Specific Gravity	Dangerous Because	Occurs
Methane occurs as firedamp	.559	explodes, burns	new works, rooms and entries, going uphill places driven ahead of air, places having no ventilation, in squeezes
Carbon dioxide occurs as blackdamp	1.529	smothers	dip workings, old work not ventilated, behind seals, return from mine fires
Carbon monoxide occurs as whitedamp	.967	poisons	in the return from smoldering mine fires, in cavities in roof, near mine fire and after fire

The only source of this gas, so far as miners are concerned, is in the charging of electric storage battery locomotives and other battery equipment. For this reason it is important that storage batteries when being charged should be in a good air current so there can be no accumulation of this gas, as it is very explosive.

Hydrogen sulphide. The next of these gases is hydrogen sulphide or "stinkdamp" and its properties are:

HYDROGEN SULPHIDE (STINKDAMP)

Chemical symbol H_2S	Will burn
Specific gravity 1.1908	Is explosive
Is a chemical compound	Extremely poisonous
Will not support combustion	Colorless
Will not support life	Smells like rotten eggs

Hydrogen sulphide occurs in the mine as a product of the burning of black powder and is found sometimes, but rarely, in blowers. It is also given off by decaying matter in swamps or waterholes. It is very poisonous in as small quantities as five-thousands of one per cent of the ventilating current. It is also extremely injurious to the eyes. It is easily detected, having a very offensive smell similar to rotten eggs. Anyone smelling this odor should get to fresh air or away from the smell.

Acetylene. The last gas to be considered is acetylene.

The following chart gives its properties:

ACETYLENE

Chemical symbol C_2H_4	Will burn
Specific gravity .906	Is a compound
Will not support combustion	Has a sharp odor
Will not support life	Colorless

The only way this gas is formed underground is by the action of water on carbide. Care should be taken that no great amount of carbide is stored underground or that water does not come in contact with a large amount of carbide at one time, as it would make enough gas to seriously burn a man. There is little likelihood of this happening, however, if ordinary precautions are observed. This gas is sometimes brought into the mine for cylinder welding and care should be used in handling these cylinders.

Water vapor. The presence and effect of water vapor in the air also affects the safety and health of the miner and the condition of the mine. If the air carries all the moisture it will hold, it is said to be saturated. Such an atmosphere is very uncomfortable, as the perspiration from the body will not evaporate and any rise in temperature will be severely felt.

The effects of the amount of water in the air also have an important bearing on the safe condition of the mine. In warm weather when the outside warm air is moist or "sticky" as we say in summer, the air is cooled on entering the mine and drops some of this moisture on the roof and ribs. This helps to keep the mine in a damp and safe condition. In winter time this condition is reversed; the cold air entering the mine is dry and as it warms up it picks up moisture from the mine, making the mine dry. This brings on a dusty condition and the danger of dust explosions is greater in the winter months. The greater frequency of serious explosions in the winter and spring months than in other months is due to this effect.

Another action is the effect of warm air on the roof. This, due to a combination of causes, makes the roof hazard during the summer months much greater than during the winter. In summer some types of slate are prone to cut because of action of the warm air, and some companies use air conditioning on their intakes to overcome this. Rock dusting, gunniting, or painting is also used to protect the top.

QUESTIONS FOR CHAPTER III

1. What is the specific gravity of methane and why is it important?
2. What three ways can a miner lose his life through contact with mine gases?
3. What is the most dangerous mine gas?
4. How may marsh gas be detected?
5. Where will it be found?
6. Is it lighter or heavier than air?
7. Why is it dangerous?
8. What mine gas poisons the most miners?
9. How can carbon monoxide be detected?
10. Is it heavier or lighter than air?
11. Where will it occur?
12. Why is it so dangerous?
13. Where will blackdamp be found?
14. What causes it?
15. Is it heavier or lighter than air?
16. How may it be detected?
17. What is the most difficult gas to clear and why?
18. What dangers may arise in charging a storage battery locomotive?
19. What precautions should be used in handling carbide?
20. What is the most poisonous mine gas?

21. Where is it found?
22. How is it detected?
23. Should gasoline pumps or motors be used underground?
24. Is a mine having fifteen per cent oxygen in the air more dangerous if six per cent of carbon dioxide is added?
25. How would you approach a mine fire?
26. Explain the action of air on a mine in summer? In winter?
27. If you were a fire boss, how would you examine a mine?

CHAPTER IV

SAFETY LAMPS

Lesson Subject:

The principle, construction, and use of devices used in testing for the presence of mine gases.

Devices to be Studied:

Flame safety lamps, M. S. A. methane detector, hoolamite carbon dioxide indicator. Use of birds and animals.

Lesson Objective:

To learn: the principle; construction, care and use of various flame safety lamps; to learn: principle and use of a methane detector and a hoolamite indicator.

CHAPTER IV

SAFETY LAMPS

In 1815 an Englishman, Sir Humphrey Davey,⁷ made the first safety lamp to be placed in use. From this early lamp, the modern Davey lamp has been developed.

Principle of safety lamp. The principle developed by Davey, which is still the one upon which the safety of modern lamps depends, is that a flame enclosed in a fine meshed screen will be cooled enough by this screen that it will not pass through and light a surrounding atmosphere that is inflammable. That is, if an inflammable mixture of gas or air is drawn into a safety lamp, the gas will be ignited and may even explode within the lamp; but the flame of such an ignition or explosion will be cooled enough by the gauze which surrounds the flame of the safety lamp that it will not light the explosive air that is outside the lamp. This safety feature is true only so long as the gauze remains cool. If this gauze or screen becomes heated too much by carrying the flame of the wick too high, or allowing the lamp to remain in a body of gas too long, the flame may pass through the gauze and set off the gas outside. For this reason,

⁷ James I. Beard, "Questions and Answers," Volume I, New York, McGraw Hill Book Company. p. 209.

flame safety lamps should be used with care in testing for gas and should be used only by persons who understand their use and care.

The original safety lamp as made by Davey consisted only of a fount or oil chamber, a wick, and gauze covering the flame. Later developments added the glass, the automatic lighter and the bonnet shielding the gauze.

Parts of a safety lamp. Today the essential parts of a good, safe testing light are as follows:

- (1) The fount or oil chamber which holds the fuel and the wick.
- (2) The glass that surrounds the flame, which allows the rays of light to be thrown off for working purposes and permits a closer inspection of the flame.
- (3) The gauze that caps the glass and prevents the flame from reaching the outside atmosphere.
- (4) The metal shield or bonnet which surrounds the gauze to protect it from injury and also to shield it from air currents of high velocity.

Besides these fundamental parts, a good flamelight also has an approved lighting device that permits the lamp to be lighted without opening, washers to make all joints air-tight, an expansion ring to allow for expansion as the

lamp becomes hot, and a good locking device. Of these secondary devices the expansion ring is the most important. This ring is usually placed above the glass as the top of the glass expands when the lamp is lighted. This ring allows the glass room to expand and also protects it if the bottom is screwed too tight.

Selecting a safety lamp. There are a number of good flame safety lamps on the market today, and the following points should be considered in selecting one for general use:

- (1) The lamp should give enough light to serve as a traveling light, if necessary.
- (2) It should be of good construction, the bonnet of strong material, and the parts of the frame should be rigid and so placed as to protect the glass from injury.
- (3) It should have double gauzes, as it has been proved that double gauzes are much safer than single gauzes.
- (4) It should have a durable and a rigid bonnet with holes so arranged that the air current cannot strike directly on the gauze.
- (5) It should have a lower gauze ring so that the air can feed to the flame from the bottom.
- (6) It should have a screw type of wick adjustment

so that the flame may be raised or lowered easily.

- (7) It should have an expansion ring.
- (8) It should have an efficient relighter.
- (9) It should have a reliable locking device.

Permissible lamps. The Bureau of Mines has the following requirements for a lamp that is submitted to them:

- (1) It must have a double gauze, the openings in the mesh of which are not more than eight hundred and forty-one to the square inch, not less than seven hundred and eighty-four to the square inch.
- (2) If standards are used, the standards must be so arranged that a straight line touching two consecutive standards will not touch the glass.
- (3) The lamp must be so constructed that it is not possible to assemble the lamp with any of the parts left out without easily detecting it.
- (4) The lamp must be equipped with an efficient locking device and a well constructed glass globe.

The construction of flame lamps for testing purposes only are essentially the same as those above, except a testing lamp does not necessarily need to be of as rugged construction as a general purpose flame lamp. It is an advantage to have a smaller lamp that can be placed close to the roof, so

⁸ "Use and Care of Miners' Safety Lamp," Miners Circular No. 12, Washington, D. C., United States Bureau of Mines.

that thin layers of gas can be detected.

There is a diversity of opinion as to the type of wick most suitable. Two types are available, flat and round, and there are points in the favor of each.

There is also much difference of opinion as to how small a percentage of gas may be detected with a flame testing light. Many authorities state that gas cannot be detected below one and one-half per cent and then only with difficulty. (It is my own belief, and I am supported in this by many fire bosses, that less than one per cent may be determined by an experienced man). The detection of a low percentage of gas comes only with practice. The beginner should be careful that he does not mistake a fuel cap for a gas cap. It might also be said that it is best to be mistaken on the side of safety, and if there is any doubt, keep on the safe side.

Care of lamps. The same lamp should be used each time by the same person, and the man using it should be responsible for its care. In cleaning, filling, and putting together a lamp, the following procedure should be followed:

- (1) All removable parts should be detached and the fuel chamber filled with naphtha or gasoline. When filling, the fluid should not be allowed to run over. In fact, most safety lamps require

only enough of either of these fuels to thoroughly saturate the cotton within the fount or fuel chamber. The naphtha or gasoline should be of good quality, having a specific gravity of 0.7 to 0.72.

- (2) The gauze should be brushed inside and out with a stiff bristle brush and blown if possible with compressed air. The gauze should be carefully examined for broken wires or enlarged holes. If any gauze is found damaged, it should be smashed and discarded. When a new gauze is installed, it should be thoroughly burned out in the lamp before being taken below.
- (3) The glass globe should be wiped clean with a clean cloth and both ends examined for nicks. The gaskets should be whole, should be fit snugly, and should be free from grit and dirt.
- (4) The bonnet should be brushed inside so as to remove any soot or dirt.
- (5) The lower ring gauze should be brushed and examined for defects.
- (6) The lighter should be tested to see whether it is in working order.
- (7) After the lamp is lighted and warmed for a minute or two, the wick should be adjusted to a low

flame, all parts put in place and adjusted, and the lamp locked. The tightness of the joints should be tested by blowing against the chimney joints while the lamp is slowly revolved.

If these directions have been followed, that is, the gauze properly cleaned, and all parts assembled correctly, it is now in condition to be used in a gassy mine and, properly used, it may be handled without danger in any kind of a gaseous atmosphere. As a further safeguard, some companies require their fire bosses to test their lamps in a box containing an explosive atmosphere before going below.

Safety precautions in using lamp. The following list of rules in handling a flame safety lamp is taken from a bulletin prepared by Pennsylvania State College⁹ for extension work:

- (1) Be sure the lamp is locked before taking it in the mine.
- (2) Take care of your own lamp.
- (3) Do not carry a key or other unlocking device.
- (4) Do not carry matches.
- (5) Do not attempt to open your testing light in the mine unless in the presence of another light.
- (6) Do not set your lamp down; it may upset and be extinguished, or damage to the lamp may result.

⁹ "Extension Course in Coal Mining," Volume I, Pennsylvania State College, State College, Pennsylvania, P. 245.

- (7) Do not allow the flame to smoke; soot may fill the gauze.
- (8) Before entering a room or "tight" end, examine the flame of your lamp and make frequent tests as you advance.
- (9) Avoid testing for gas while shots are being fired close at hand, as the concussion may knock the flame through the gauze.
- (10) When the gas flames on your lamp, withdraw the lamp slowly, smother it, and return it to fresh air before attempting to relight it.
- (11) If your lamp flames and the wick goes out, be sure to examine the gauze, because the gas may still be burning within the gauze.
- (12) Having detected gas, do not repeatedly put your lamp back into it.

The following paragraphs are also taken from the same bulletin:

Testing for Gas (Methane) with the Safety Lamp.

The detection of gas on the flame of a safety lamp consists of noting the lengthening of the flame due to the burning of the gas in contact with the flame. There are three general methods of testing employed by persons authorized to handle safety lamps:

- (1) By using the normal flame, such as is used for lighting purposes. For even approximate detection the height of the flame or length of the flame in fresh air should first be noted, after which the increase in flame length due to the presence of gas will indicate the percentage of gas present. This method can only be an approximation, as fresh air may be some distance from the gaseous mixture tested, and accurate results could be obtained only by use of a measuring device to show the lengthening of the flame. Less than three per cent of gas would not be shown unless a marking device was used. This type of test is used quite often by machine

men or helpers in testing for gas before preparing to cut a coal face.

- (2) By using a short or intermediate flame, about one-half the length of a normal lighting flame. The same difficulties found in accurate testing with the normal flame are present with this type of flame also.
- (3) By using a "cap" flame which is blue, rather than yellow in color; it is also called a non-luminous flame. By this means, the presence of more than one per cent of gas may be detected under ordinary conditions. This type of test does not require observation of the testing flame in fresh air first, hence, it is the most suitable for testing for small percentages of gas.

Adjustment of Normal or Short Flames. Oil lamps frequently have the flame shortened and a crust accumulates as the wick burns. This requires frequent adjustment of the wick, at which time the pricker is used to dislodge the crust and the end of the wick is snuffed. Long practice has taught the miner to maintain the flame at a height which will provide a good light, and this, the normal flame, is the one frequently used for testing purposes.

Naptha or gasoline lamps do not have trouble with a crust on the wick, but the heating of the fount or fuel container has tendency to increase the length of a normal flame, requiring frequent adjustment of the wick. Still air naturally allows more heat to accumulate and the flame has a greater tendency to increase in length than in a rapidly moving air current. Testing for gas under four per cent with a normal or short flame requires adjustment of the height of the flame in fresh air, regardless of whether the lamp burns oil or naptha or gasoline.

Use of the "Cap" or Non-luminous Flame. The "cap" flame is by far the most reliable for gas detection since it requires no previous adjustment in fresh air. The normal flame is reduced until the yellow color disappears and a blue flame remains. This

does not interfere with seeing the "gas cap" unless the miner has nystagmus or other eye trouble.

The height of the "gas cap", of course, is the measure of methane content in the air, each type of lamp giving different heights of caps. For instance, a flat wick will not necessarily give the same result as a round one. Two lamps burning two different kinds of fuel will not give the same flame height in the same gas mixture. The temperature of the flame governs the height of the cap, and the temperature depends upon the nature of the fuel used. The proper procedure is to have each person authorized to carry a safety lamp issue and be given the same lamp every shift; then have that person test his lamp frequently in gaseous mixture of known methane content; in this manner, more accurate results will be possible for everyday testing.

Quite often a small "cap" is noticed in fresh air over the regular "cap flame". This is due to the heat of the flame turning some of the fuel into gas which forms the "fuel cap". This cap depends on the kind and quality of fuel being used and is quite distinct in a naphtha or gasoline burning lamp. Practice in fresh air in observing this fuel cap will remove the tendency to count it as a gas test since it has a round or mushroom appearance whereas a gas cap has a pointed appearance.

It is exceedingly dangerous to place willfully a safety lamp in an atmosphere containing more than five and one-half per cent of methane or other explosive gas. Tests have indicated that even permissible safety lamps under certain conditions (exaggerated gas content, high velocity, long exposure) are not safe; hence proper handling is very important in its safety, and use of the lamp under extreme conditions constitutes a hazard.

Frequently, fire bosses, assistants, and mine foremen, persons who should be able by reason of their long experience to detect methane with some degree of accuracy, have failed to detect gas within one per cent of its correct proportion in air as indicated by an approved methane detector. On the other hand, there are instances of persons who

have successfully detected methane as low as three-tenths of one per cent of the flame safety lamps, the result being checked by an approved methane detector. This would indicate the necessity of having all persons on whom there is any responsibility for the detection of gas in mines undergo a regular examination on their gas-testing ability with the flame safety lamp, the tests being checked with an approved methane detector. In this manner, the fire boss or other responsible persons, should have his gas testing ability sharpened by the comparison with the methane detector instead of relying on older methods of determination of gas content.

Making examinations. After the fire boss has properly prepared his lamp, he should first examine the fan chart, if a recording device be kept on the fan, to see that the fan is performing properly and that there has been no sudden change in pressure. Falls and partial stoppage of the ventilating current can sometimes be spotted from the chart of fan performance. The fire boss should then take a barometer reading. For the fire boss's benefit, the barometer should be read and recorded at least five hours before he comes on a shift. By comparing these two readings and observing whether the barometer is rising or falling, he can, if he is well acquainted with his mine, somewhat forecast the conditions he will find below. A falling barometer will indicate an increase of gas in the return and at the working faces. Sealed areas in the mine will also blow heavily owing to the change in atmospheric pressure that the falling barometer indicates.

A good average reading for a barometer in Indiana mines is 29.5 and twenty-nine to 28.5 indicates a serious low. During periods of pronounced lows, everyone in the mine should be especially vigilant in regard to ventilation and gas, as there is a great increase in the amount of gas given off in a mine during such a low. Particular attention should be given to seals during such a period.

There can be no definite rule given as to the route a fire boss should follow in examining a mine. When he first goes below, he should check his return at the bottom; then the course of his examination will be determined by the state law and the physical characteristics of the mine. For safety, a fire boss should always examine with the air, thus insuring a fresh air supply. Many fire bosses examine against the air, as it is cooler walking, but this is a bad practice, especially in mines where blackdamp is encountered frequently. Places that are believed by the fire boss to be dangerous should be examined at the start of his shift and again at the close of his examination before he goes on top to report the mine. In examining, remember the physical properties of the gases, and look for firedamp next to the roof, in up-hill places, in working places ahead of the air, over falls, in areas on the squeeze and in old works where the ventilation is poor. He should watch the air in the mine, especially the current.

Experience will help to teach one to judge the amount of air moving in each part of the mine; and if the quantity of air does not seem right, he should look at once for an open door or a fall that may have blocked the ventilation.

A fire boss should watch swamps, old workings, and any works in which the air has not been circulating for the accumulation of blackdamp. He should never go down a shaft that is not working without testing for blackdamp from the surface. A fire boss should never approach a mine fire on the return side. Fires may be easily detected by the sense of smell, and if a fire is suspected, approach it on the intake side.

He should keep on the alert for any change in the physical conditions of the mine. If time permits, examine the top carefully, watch the pillars in working panels closely, especially if the section is about worked out, as the condition of the pillars will predict more accurately than broken props the approach of a squeeze. Often props are broken by bottom coal or fire clay having heaved, especially if the bottom has become wet, before much weight comes on the panel.

How to safely predict the time and speed of a squeeze comes only with long experience and knowledge of the mine in which the squeeze is occurring. Squeezes act differently in

various mines and sometimes differently in different localities of the same mine. The action is determined largely by the thickness and nature of the overburden. However, in any mine if a working panel begins to have sharp "snaps" or "bumps" in the strata over the seam and there is a continued dripping of small particles of slate from the roof, it is safe to say that panel is no longer safe to be worked. In squeezes, as in all other safety questions, it is best to be on the safe side. It is foolish to take physical risks and also to risk losing thousands of dollars worth of material for the sake of a few more tons or days loading in the section.

A fire boss should always be thorough in an examination. The fact that he has examined a place a hundred times and never found gas is no indication there will be no gas there the next time. He should examine every day, as thoroughly as if that were the first time an examination had been made for a month and nothing was known as to the condition of the mine. The fire boss, more than any other man in the coal mine, can make no guesses; he must know and be responsible for the safe condition of the portion of the mine in his charge when he reports it safe.

Mechanical detectors.¹⁰ There are a number of mechanical

¹⁰ J. J. Forbes and G. W. Grove, "Mine Gases and Methods for their Detection", Washington, D. C., United States Department of the Interior, 1938.

methane detectors in use today, the one sold by the Mine Safety Appliance Company being the most popular. This new methane detector, which is already approved by the U. S. Bureau of Mines, is designed to test mine air for methane quickly and accurately. It is direct reading, completely self-contained, light in weight, and very easily operated.

A sample of mine air is taken into this instrument by squeezing an aspirator bulb which serves as a suction unit and prevents any lag in obtaining the readings.

The auto-potentiometer electrical circuit gives the detector a high degree of sensitivity and accuracy, so that concentrations of methane in mine air as low as 0.05 per cent can be detected accurately. Concentrations of methane as low as 0.01 per cent have been estimated with a fair degree of accuracy. There are two scale ranges on the indicating meter, one of which reads from zero to five per cent methane, graduated to 0.01 per cent, and the second scale which reads from zero to two per cent methane, graduated to 0.05 per cent methane.

When less than two per cent methane is indicated in preliminary tests, the scale reading from zero to two per cent of the methane is to be used in order to obtain more sensitive and accurate readings. A toggle switch in the electrical circuit--located on the top panel--makes it easy for the operator to change quickly from one scale range to the other.

In use two platinum wire filaments in the instrument are heated to a definite temperature by current from the electric cap lamp battery, and one of these filaments is exposed to the action of the gas sample. Methane in the sample is oxidized or burned on this platinum wire, and the increase in temperature from the combustion increases the electrical resistance of the wire in proportion to the amount of methane present. This increase in resistance from the burning of the methane is indicated by the millimeter, the scale of which is calibrated to give readings directly in terms of per cent of methane. Accurate readings can be made in air currents in which sampling may be done, since the sample is under positive suction from the aspirator bulb and there is no dependence on the principle of diffusion.

In all gas detectors operating on the "hot wire" principle, the zero setting of the meter is disturbed by a decrease in the battery voltage and by the evaporation of the heated platinum wires. However, in the M. S. A. methane detector, the zero setting can be easily and quickly adjusted, even in a gaseous atmosphere, by means of a special current check arrangement without the necessity of returning to fresh air. The current check arrangement in the instrument insures both a definite initial temperature and applied voltage at the detector unit, so that the sensitivity and accuracy of the active platinum wire filament in the detector is constant

during its life. There are two models of this detector. Type A. P. 5 contains two No. 6 dry cells in the same box with the meter and has no light attachment. Type A. P. 6 is combined with an Edison battery and cap lamp.

Carbon monoxide detectors.¹¹ In sampling for carbon monoxide, the use of small animals, especially canaries and mice, has long been recognized as a means of detecting the presence of carbon monoxide in the atmosphere. Canaries are kept as part of the standard rescue equipment of the Bureau of Mines and are also kept by some of the larger mining companies. Many tests have been made in relation to the use of small animals for carbon monoxide detection, and much has been written on the subject. The tests show that they may be used repeatedly in mines to indicate the presence of carbon monoxide without danger of losing their susceptibility to that gas.

Up to the present time, canaries have been the best of all living detectors. Their greatest advantage over the common mouse is that they are more accustomed to human beings and are more naturally active in their presence. The mice, being easily frightened, will crawl into a corner of the cage and remain quiet. In this condition they must be observed

¹¹ J. J. Forbes and G. W. Grove, "Mine Gases and Methods for their Detection", Washington, D. C., United States Department of the Interior, 1938.

closely to detect any poisoning effect. On the other hand, the canary becomes more active when frightened. This activity will quickly reveal any unsteadiness in its condition due to the effects of gas. Canaries are usually easily obtainable and, if handled intelligently, will seldom die as a result of exposure to an atmosphere containing carbon monoxide.

The main objection to the use of such subjects for carbon monoxide detection is the physical difference which may exist between two subjects, even of the same species. Because of this, if living detectors are to be used, their resistance to the effects of carbon monoxide should be tested before they are put into actual use. One canary may be more resistant to the effects of carbon monoxide than another. Frequent observation has proved this to be a fact, and for this reason an accurate mechanical detecting device, such as the hoolamite detector, is always preferred to the more variable living detectors.

Hoolamite indicator.¹² The hoolamite or activated iodine pentoxide indicator for carbon monoxide is used in rescue and recovery operations. This device, to a great extent, has been replacing canaries and mice in rescue and

¹² J. J. Forbes and G. W. Grove, "Mine Gases and Methods for their Detection," Washington, D. C., United States Department of the Interior, 1938.

recovery operations, since it requires less care and attention under the same conditions and is more accurate.

Hoolamite, the material used in the indicator, is a mixture of iodine pentoxide and fuming sulphuric acid on granular pumice stone. When in contact with carbon monoxide, iodine is liberated and the white granules of hoolamite change to bluish green, deepening in color to violet-brown and finally to black. The color is dependent on the concentration of carbon monoxide.

The complete indicator consists of:

- (1) A metal barrel filled with activated charcoal through which the air is drawn before entering the hoolamite tube.
- (2) A rubber hand bulb containing a valve which causes the air to be drawn into it through the activated charcoal and expelled through the hoolamite.
- (3) The glass tube containing hoolamite.
- (4) The color tube, having five permanent colors in pumice stone, graduated from 0.10 to 1.0 per cent of carbon monoxide and held in place beside the hoolamite tube for ready comparison.

It has been found that various gases, other than carbon monoxide, will also readily affect the hoolamite if some method is not adopted to prevent it. For this reason,

the tube containing the activated charcoal is interposed between the intake and the hoolamite. This charcoal will extract all gases except carbon monoxide contained in the atmosphere that will affect the hoolamite.

All of the organic compounds capable of oxidation, with the exception of methane, react with hoolamite. This would seem to indicate that hoolamite may be used for determining many gases and vapors other than carbon monoxide. This matter has not been thoroughly investigated as yet.

QUESTIONS FOR CHAPTER IV

1. What is meant by a working or testing lamp?
2. What is the principle of flame insulation discovered by Davey? Describe the make-up of the original Davey lamp.
3. What are the advantages of the features that have been added to the Davey lamp?
4. What are the essential features of a modern safety lamp?
5. Describe the gauzes used in safety lamps today.
6. What features should the bonnet and standards have?
7. What does the Bureau of Mines require of safety lamps?
8. Describe the cleaning, filling, and reassembling of a safety lamp.
9. Why should a fire boss always use the same lamp?
10. What are some of the failures that may make a safety lamp unsafe for use in a gaseous mixture?
11. Will all naphtha burning lights give the same cap height for the same percentage of gas?
12. What bad feature does naphtha have when used for a fuel in a testing lamp?
13. Describe the procedure in testing for gas.
14. Where is marsh gas found?
15. Where would one expect to find carbon dioxide?
16. Where would carbon monoxide ordinarily be found?
17. For what things must a fire boss be constantly watching?

CHAPTER V

MINE GASES AND VENTILATION

Lesson Subject:

Ventilating systems, and what is necessary to have a good ventilating system.

Instruments used in measurements of ventilation and ventilation standards.

Types to be Studied:

Natural ventilation, artificial ventilation, blowing and exhaust system, plans of development for proper ventilation.

Instruments to be Studied:

Barometer, thermometer, hygrometer, water gauge, and anemometer.

Lesson Objective:

To learn: the best ventilation system, the proper standards of ventilation, the correct use of ventilating instruments.

CHAPTER V

MINE VENTILATION

The past chapters have described how dangerous or noxious gases are produced. It has been shown that in the passage of normal air through the mine, oxygen is absorbed by the coal or used up by the breathing of men and animals, the burning of lights, and the oxidation and rotting of mine materials. It has also been shown that this air current while loosening its oxygen content is also made foul by the addition of carbon dioxide, methane, and other gases produced by various agencies in the mine.

From these facts it is readily seen that no feature of coal mining is more important than proper ventilation at the face, for the health and safety of the miner depends directly upon the condition of the atmosphere in which he works. It is not sufficient that an ample quantity of air is introduced into the mine for its needs; but it is also necessary that this air be conducted to all openings and working faces in quantities sufficient to comply with the state mining law and to provide fresh air and proper ventilating conditions for men and animals. There must also be enough air to avoid excessive moisture and to dilute, render harmless, and remove explosive and noxious mixtures or gases.

Air required. The statutes of the State of Indiana (page 21, paragraph 1, Sec. 10) reads as follows:

"The operator of every mine shall provide and maintain, hereafter, for every such mine, a sufficient amount of ventilation affording not less than one hundred cubic feet of air per minute for each and every person employed therein, and three hundred cubic feet per minute for each mule, horse, or other animal, in said mine, measured at the intake of the split or subdivision of the air, and as much more as the circumstances require. It shall be forced and circulated around main entries, cross entries, and working faces throughout the mine, so that all open places shall be free from standing gas of whatsoever kind, to such an extent that the entire mine shall be in a fit state at all times for the men working therein, and will render harmless all noxious or dangerous gases generated therein."

To comply with these standards, the limit of the percentages of gases that is to be allowed in the ventilating current must be established before it is considered noxious or dangerous. These standards are not fixed by law in this country as they are in Europe. Certain per cents, however, have been recommended by the U. S. Bureau of Mines, and the larger mining companies have adopted and accepted them as standards. Mine returns are considered satisfactory when no trace of CO or H₂S is present, the content of CH₄ is below one-half of one per cent, CO₂ is not over one per cent, and the oxygen content is not lower than nineteen per cent.¹³

¹³ "Mine Safety Board, Decision No. 8", Information Circular No. 6198, Washington, D. C., Superintendent of Public Documents. November, 1929, p. 9.

If the return in any split which ventilates any group of workings is over one per cent, it is a dangerous condition. Any working place is considered in need of added ventilation when a lamp held in any part of the room not nearer than four feet from the face and ten inches from the roof shall indicate more than one and one-half per cent of CH_4 . Also, if a working face shall be found to contain over two and one-half per cent of inflammable gas, it shall be considered unsafe and no one should enter it except a person properly protected and designated to improve the ventilation.

Requirements for good ventilation. To meet these requirements there are essentials in a ventilating system. The first of these is to have proper air courses of such size and condition as to allow the passage of a sufficient quantity of air. The size of these entries will be determined by the number of entries to be driven, that is, whether a 2, 4, or 6 entry system of development is used, the probable life of the mine, and the extent of the territory to be mined. Such entries should be driven at least ten feet wide under any condition and from twelve to sixteen feet is more often recommended.

The next necessity is a definite intake and return system. All coal mines meeting the requirements of the state law have two separate openings, one of which is the intake

downcast and the other is the return and upcast. For the coursing of the air from these two openings, development work should be planned in view of conducting the ventilating current through a series of entries through all the workings and returning it to the upcast through other entries. This is as much of a problem as haulage and should be carefully planned when the mine is first sunk.

The third essential for a ventilating system in a mine is a method of artificially circulating the air. Mine ventilation is divided into two classes, natural and artificial. In natural ventilation the ventilation depends upon:

- (1) Diffusion of the gases.
- (2) Wind pressure on the openings of the mine-- one of which may be facing the wind.
- (3) Or the difference in weight of the air in the two openings and the difference in elevation.

Of these, the third is the most important. In small truck mines if a difference in elevation does not exist, a wooden stack is sometimes built over one of the openings. In deeper mines this action is aided by the difference between the weight of the air in the intake and return due to the difference in temperature. Such a system of ventilation is very uncertain. If the outside is cooler than the mine air, the air current will flow out the higher outlet; but if the outside atmosphere is warmer than the mine air, the air will

reverse and the lower opening will become the upcast. Such a reversal of air current, which at times can be very rapid, can bring about a very dangerous condition, even in a small mine, and for this reason some system of mechanical ventilation should be used even in the smaller mines.

Five instruments are used in connection with mine ventilation in order to observe and measure the effect of the ventilating system and its efficiency. These are the barometer, the thermometer, the hygrometer, the water gauge, and the anemometer.

Barometer.¹⁴ The first of these, the barometer, is used to measure the variation in the pressure of the atmosphere. The normal atmospheric pressure is 14.7 pounds per square inch at sea level, exerted on the earth's surface by the weight of the air above. This pressure may vary as a result of differences in elevation and of atmospheric change. Such a variance of atmospheric pressure will greatly affect the amount of gas given off by coal faces and by seals in a mine, for, as the pressure is lowered, more gas will be allowed to escape owing to lessened pressure. For this reason, the barometer is used to measure these changes.

There are two types of barometers in use, the aneroid

¹⁴ "Coal Mine Ventilation," Washington, D. C., Federal Board for Vocational Education, 1931.

and the mercurial. The mercurial consists of a glass tube about thirty-four inches long filled with mercury. This tube is open at one end and, after being filled, is inverted and placed with the open end downwards in a small vessel filled with mercury. In this position the column of mercury will fall to a certain distance from the upper closed end, and the height of the column left in the tube will be approximately thirty inches. This column of mercury is now held in the tube by the atmospheric pressure on the surface of the mercury in the vessel, and the space in the upper end of the tube is a vacuum. Any change in atmospheric pressure will cause the mercury to move up or down in the tube, and the tube being graduated in inches, the change in pressure can be determined.

The pressure of the atmosphere at sea level is 0. F. and averages about 14.7 pounds per square inch. Dividing 14.7 by .49, the weight in pounds of a cubic inch of mercury, gives thirty which represents the height in inches of a column of mercury required to balance the weight of the air at the temperature at that elevation. Also the weight of the atmospheric pressure can be secured by multiplying the height of the mercury column by .49. Also the reading on a barometer will vary about one-tenth of an inch for each one hundred feet. Suppose for instance, the approximate depth of a shaft was desired. If the barometer twenty-nine inches

at the surface reading and 30.2 inches at the bottom reading were used, the difference between the readings would be 1.2 and 1.2 times one hundred equaling twelve hundred feet or the approximate depth of the shaft.

Thermometer.¹⁵ Thermometers are used in mine work to ascertain any temperature change in the return or in old gobs that are expected to heat. They are also used to measure the temperature of sealed areas where a fire has started or where a fire might be expected. Thermometers come marked either fahrenheit or centigrade scale. On the fahrenheit scale freezing is marked at thirty-two, on the centigrade at zero. Boiling on the fahrenheit scale is two hundred and twelve and on the centigrade one hundred. In order to change a fahrenheit reading to centigrade, the formula is $5/9(F-32)$ and to change from centigrade use $9/5 + 32$. Another useful formula that gives the weight of a cubic foot of air at any temperature and pressure - $\frac{1.3272 \times B}{460 + T}$, where B equals the barometer reading and T the temperature.

Hygrometer.¹⁶ Another type of thermometer used is the wet bulb thermometer, which is a standard thermometer with its

¹⁵ "Coal Mine Ventilation," Washington, D. C., Federal Board for Vocational Education, 1931.

¹⁶ Ibid.

bulb covered with a cloth sack. When this is wet and the thermometer is placed in a moving current of air or is whirled through the air, the bulb is cooled as a result of evaporation and the temperature drops. The reading thus obtained is called a wet-bulb reading, and the difference between this and a dry-bulb reading is called the depression of the wet bulb. From this, the amount of saturation in the air can be determined by the use of tables. This combination of wet and dry bulb thermometers makes what is termed a psychrometer and is usually arranged on a board with a handle so that it may be whirled in the air.

Water Gauge.¹⁷ The water gauge is one of the simplest instruments used in mine ventilation. It consists of a U-shaped tube about half filled with water. Both ends are open and a scale is attached between the tube sides. As pressure is necessary to circulate air through a mine, the water gauge is used to determine such differences in pressure. If a rubber hose is placed on one end of the U tube and run through a stopping between the intake and return air courses, the difference in pressure between the two entries will lower the water in the tube on one side and raise it on the other. This difference between the two elevations would be the reading

¹⁷ "Coal Mine Ventilation," Washington, D. C., Federal Board for Vocational Education, 1931.

of the water gauge. This may be measured from the scale or measured with a rule.

Water-gauge readings are always reported in inches, but it is important to know the pressures corresponding to water-gauge readings. If a cubical box were built one foot on a side, inside measurement, and filled with water, the weight of the water would be 62.5 pounds. The area of the bottom of the box is one square foot, hence the pressure on the bottom is 62.5 pounds per square foot. If the box had only one inch of water in it, the weight would be 62.5 divided by twelve or 5.2 pounds and the pressure 5.2 pounds per square foot. Therefore, one inch depth of water exerts a pressure of 5.2 pounds per square foot, and hence every inch of water-gauge reading represents a pressure of 5.2 pounds per square foot. This method of obtaining pressure expressed as a formula is: $p = 5.2 i$, in which "p" equals pressure in pounds per square foot and "i" equals the inches of water gauge. In other words, the unit pressure, in pounds per square foot, is equal to the water gauge reading multiplied by 5.2.

In modern plants recording pressure gauges are generally installed in the fan house. Such gauges operate on the same principle as a barograph, except that instead of the pressure of the atmosphere, it is the pressure of a blower fan or partial vacuum produced by an exhaust fan that causes

the record to be made. Through an internal mechanism operated by a diaphragm, pressed by the air, a pen traces a curve on a chart which is driven by clockwork. The mechanism is arranged so that the markings will correspond to the readings of the water gauge. Such recording gauges are most valuable to indicate immediately any dangerous short circuiting of the air under ground or the stoppage of an important airway by a fall of roof. Also, if an explosion occurs in the interior of the mine, it is immediately indicated by a sharp peak in the line traced by the pen on a chart. The mining laws of most coal-mining states require the use of such gauges. They are usually placed in the engine room of the fan house and connected by a pipe which opens into the fan drift.

Anemometer.¹⁸ The anemometer is an instrument used in mine work to determine the velocity of the air current. It resembles a small disk mine-fan in construction. When the air strikes the fan blades, it causes them to revolve and the instrument is so geared as to indicate on the dials the number of feet of air passing through it. In use the instrument is held in the air current for one minute and then the dials are read. This reading is the velocity of the air in feet per minute, and this, multiplied by the area of the

¹⁸ "Coal Mine Ventilation," Washington, D. C., Federal Board for Vocational Education, 1931.

entry, is the number of cubic feet per minute that is passing along the entry. The formula $Q = AV$ expresses this, that is, quantity = area times velocity--the area being determined by use of a tape and the velocity secured by use of an anemometer. This is the most useful formula in mine ventilation.

Velocities that are too slow to be measured by use of the anemometer may be measured by measurement of the speed at which smoke travels in the air. Two persons are required to do this and a distance, say one hundred feet, is measured off on the entry. Fuse or powder is then burned at the intake end of the measured distance, and then the time is secured that it takes for the smoke to travel the distance measured. Also part of the entry may be bratticed off with curtains and the velocity increased enough, in a small opening, to turn the anemometer.

Psychrometer.¹⁹ The ordinary stationary hygrometer which is merely a dry bulb thermometer can be used with a fair degree of accuracy when the velocity of the air current is three hundred feet or more per minute. If it is less than this, a sling psychrometer should be used. The standard form of sling psychrometer is that devised by the United States Weather Bureau. This type is unprotected and would be easily

¹⁹ "Coal Mine Ventilation," Washington, D. C., Federal Board for Vocational Education, 1931.

broken in a mine. The usual type is that used by the United States Bureau of Mines. This has a handle to which the frame of the instrument is attached by a swivel. The handle is grasped in the hand and the psychrometer whirled rapidly. This produces the same effect as if the psychrometer were held in a strong current of air. As previously described, these instruments have a dry bulb thermometer and a wet bulb thermometer, the latter having a wet muslin cap. The water of this cap, in an atmosphere that is not fully saturated, evaporates in proportion to the degree of saturation, thus cooling the bulb. This is because the effect of a liquid vaporizing is to cool adjacent objects; so the wet-bulb thermometer reads lower than the dry-bulb thermometer. The difference is read and referred to a table that indicates the relative humidity at the point of the test. The test should be repeated several times to insure accurate figures.

The use of the hygrometer and sling psychrometer came into prominence some years ago in an attempt to humidify the mine air in the winter. In mines, except in the arid climate of the Rocky Mountain coal fields, the dust is damp in summer near the intakes and exceedingly dry in winter. This is due to the difference in moisture carried in or taken out of the mine by the ventilating current.

Water vapor. An air current which is only partly

saturated is a good drying agency. The drying of wet clothes hung in the wind illustrates this fact. They soon become dry. The moisture from the clothes is evaporated. If an air current enters a mine at a temperature considerably lower than that of the mine, it carries out of the mine immense quantities of moisture coming from the strata. Even if the cool air goes into the mine fully saturated, when it is heated by the mine walls it becomes undersaturated at the higher temperature. Hence it absorbs moisture along its path and usually becomes saturated before it leaves the mine. Consequently the air current carries moisture out of the mine, leaving coal dust present in a very dry condition and a very dangerous one, if it is not properly treated by rock dusting. This is what happens in the cold or winter months of the year, and it produces conditions ideal for the propagation of a dust explosion, if thorough rock dusting has not been done in accordance with the state law or the recommendations of the United States Bureau of Mines.

In the summer time when the intake air may have a temperature of 100°F. and is forced into a mine whose temperature is about 60°F., the temperature of the entering air is gradually reduced to that of the mine. As the temperature of the air is reduced, the capacity of the air for carrying moisture is likewise reduced and the excess moisture is deposited on the sides, roof, and floor of the mine.

Humidifying the mine air by exhaust steam from fan engines, hoisting engines, compressors, and similar equipment has been tried for the purpose of keeping the dust in the mine from becoming excessively dry and therefore more subject to ignition. Boiler plants have been erected for no other purpose than to raise steam for humidifying purposes. Some companies have installed radiators in the fan intakes or in the intake airway to heat the air before humidifying, thus increasing its capacity to absorb water from sprays or wet curtains. In other mines steam jets have been used which both heat the air and give moisture. There is less tendency to fog the air when it is heated before the steam is turned into it. There is some claim that in mines not humidified the natural alternation in winter and summer of dry and moist condition of the intake causes the roof to slack and fall. Other mines pass their intake air through cold sprays of water in summer in order to keep it as near an average temperature as possible and to avoid roof cutting.

Although watering is no longer regarded as an efficient method of preventing dust explosions, there is a growing tendency today to consider the establishment of a certain degree of temperature and the humidification of the ventilating current as desirable to obtain uniform atmospheric conditions in the ordinary shallow mines in summer and winter, and to lessen the damaging effect of alternation

of wetting and drying on the mine roof. Some coal mining companies are seriously considering the merits of humidifying with this objective in mind. Humidification lessens the drying of the coal dust and cuts down the requirement for rock dusting.

As has been previously mentioned, there are two types of ventilation, natural and mechanical. As natural ventilation is unsatisfactory and seldom used, some method of artificial ventilation exists at practically all mines. The first of these to be used was furnace ventilation. In this system a brick-enclosed fire grate was used to heat the column of outgoing air. The fire grate was placed, in or near, the upcast shaft and always ventilated the mine by the exhaust system. The temperature of the air in the upcast being raised several hundred degrees by the furnace would be much lighter than the cold air in the downcast. The use of a furnace was never considered safe in a gaseous mine, and few are now found in use.

Ventilating fans. Today the only practical use of extensive ventilation is by the agency of fans and this means is required by all state laws in mines employing more than a few men. Mine fans are classified into two types, the screw type and the propellor type. The screw type is usually in the form of a desk fan and resembles an anemometer or an

ordinary house fan. These fans are light, cheap, easily moved, and are good for emergency use. They are very limited as to the pressure they will overcome and hence in the quantity of air they can circulate. As a rule, they will not work against a water gauge of over one inch.

The propellor type is the centrifugal fan and is the most efficient. In this type, the air is drawn in at the central part of the fan from one or both sides and turned toward the blades. The air entering between the blades by the application of the centrifugal force imparted by the rotation of the fan is thrown off at a high velocity by the blade tips. These fans are also divided into two classes, the forward and backward curve fans, this designating the curve of their blades. However, space does not permit the discussing the merits of each.

Blowing and exhaust systems. Two methods of circulating the air through a mine are also practiced. In one, the blowing system, the air is forced through the mine by a fan which blows the air into the mine. In the other, known as the exhaust system, the air is drawn out of the mine by the fan. Both are equally efficient, but the blowing system is most usually used due mainly to the desire to keep the hoisting shaft free from ice in the winter and the bottom as warm as possible to facilitate the handling of cars.

Fan locations. Mine fans should always be placed on the surface although they are more efficient if placed below. If below, the fan would be likely to be destroyed by an explosion or fire, and there would be no way of ventilating the mine for recovery operations until another fan was installed. Mine fans should always be placed at one side of the mine shaft, and there should be explosion-relief doors opening the full area of the shaft and in direct line with it. There should also be explosion-relief doors in the fan conduits. The fan, the fan house, and the fan drift should be built of fireproof material and substantial construction.

Trap doors should be arranged, so that in case of need the direction of the air from the fan could be reversed. If possible, two sources of power for the operation of the fan should be available. Either steam or electricity may be used. Both have their advantages and disadvantages, although modern installation favors the electrically driven fan.

QUESTIONS FOR CHAPTER V

1. Why is mine ventilation needed?
2. What are the requirements of the state law of Indiana in regard to ventilation?
3. Would a mine always be safe if this amount of air was circulated through it?
4. Who is the proper authority to designate how much air must be circulated through the mine?
5. Is there any danger in operating a small mine without some method of mechanical ventilation?
6. If the fan should suddenly break down in a mine that was gassy, what should a mine foreman do?
7. What is the highest per cent of CH_4 allowable on the return, of CO , of CO_2 , of H_2S ? What is the highest per cent of CH_4 allowable on a panel split? Beyond what per cent of CH_4 should a fire boss mark off a room?
8. What are the requirements in Indiana in regard to mine openings?
9. What instrument is used to measure atmospheric pressure?
10. What is the atmospheric pressure at sea level?
11. How many inches of mercury is this?
12. If the barometer reads twenty-eight inches, what would the atmospheric pressure be?
13. How much does the barometer vary per hundred feet?

14. Of what practical use is the barometer in the operation of coal mines?
15. Describe the construction and use of a water gauge.
16. If a water gauge reads twenty-four inches, what unit pressure does it show?
17. If the mine water gauge usually registers two inches and one morning it is found registering four inches, what would probably be the cause?
18. If, on the other hand, it only registered one inch, what would you suspect?
19. If the pressure producing ventilation in a mine was twenty-five pounds per square foot, what would the water gauge be?
20. What is the water gauge reading at your mine?
21. What is the anemometer and for what is it used?
22. How many readings should be taken to get the true velocity?
23. If an entry is ten feet wide and five feet high and the velocity three hundred feet per minute, what quantity of air is passing?
24. Name another way of measuring the air velocity.
25. What does the state law require with reference to measuring the air in Indiana?
26. Explain the formula $Q = AV$.
27. Describe briefly furnace ventilation.

28. Can a furnace create a force system of ventilation?
29. Is there any danger of passing mine air over the furnace?
30. Do the laws of Indiana prohibit the use of furnaces?
31. What are the two systems of ventilating a mine by fans?
32. What is the principle of the blowing system?
33. Name some of the advantages and disadvantages of the blowing system.
34. Name some of the advantages and disadvantages of the exhaust system.
35. What are the disadvantages of having crushers or screens built over a mine intake?
36. What are the two types of mine fans?
37. What are the two types of centrifugal fans?
38. How should a mine fan be installed?
39. What is a booster fan?
40. When should a booster fan be used?

CHAPTER VI

METHODS OF VENTILATION

Lesson Subject:

The control and direction of ventilating currents.

Structures to be Studied:

Stoppings, doors, overcasts, undercasts, and regulators.

Lesson Objective:

To learn: the proper use and placing of stoppings, doors, overcasts, and regulators. To learn the value of ventilation splits.

CHAPTER VI

METHODS OF VENTILATION

The body of air which is moved through the mine to keep it free of gas and in a workable condition is called the ventilation current, and in order to have a continuous current that reaches all faces and openings it is necessary to direct its movements. This direction is accomplished by the use of stoppings, doors, overcasts or undercasts, regulators, and line brattices.

When the ventilating current is first conducted into the mine, it passes through a shaft, slope, or drift. The passage through which the air enters the mine is called the intake, and the passage through which the air is returned to the outside is called the return. These openings from the surface may be lined with brick, cement, or wood, and it is important that the passages have sufficient cross-section area to keep the velocity of the intake air as low as possible, as any power losses by reason of improper size will assume huge proportions in years of operations. It is very important that the right-sized shaft be selected.

At the bottom of the intake it is also important that the air current be deflected from its original course and started into the mine entries by as smooth corners as possible. It has been proved by experiments that as high as twenty per

cent of the power used in ventilating²⁰ a mine is used up by the passing of air around sharp curves or angles in an airway. To eliminate this as much as possible, it is the best policy to round off the openings into the air shaft and also to round off the corners or use air vanes in the entries meeting the intake shaft bottom.

In coursing the air from the bottom, the system of mining used will determine the method used. In general, the six-entry method of development is recommended. By such a plan, the air can be split to the different parts of the mine at the bottom thus keeping all future seals on the intake. In flat-seam mining a great deal of preliminary drilling is necessary to secure elevations before the working plans of the bottom are made.

As the working entries are advanced, it is necessary to close the openings that are made between the intake and return for face ventilation. These are usually closed first with temporary stoppings that may consist of a board frame covered with brattice cloth, a pack wall of rock or slate, or constructed entirely of lumber. These temporary stoppings are in turn replaced in all but room entries by stoppings of tile, brick, stone, or concrete. Table IV shows a relative

²⁰ C. A. Herbert, "Some Factors Effecting Mine Ventilation," Indiana Coal Mining Institute, 1934.

comparison of different materials.²¹ In this table a comparison was made as to first costs, strength, and tightness of stoppings constructed of different materials. In the comparisons made the stopping of lowest cost was rated 1, that of greatest strength 1, that of greatest tightness 1, and the others rated from this point. A study of table IV will show that the most satisfactory stopping from the standpoint of durability, strength, low maintenance, and lightness is one which is constructed of brick or paving brick. These stoppings should be built with a layer of wood blocks on top to prevent cracking, and if the stopping is of fairly short life, a lime cement mortar may be used to permit the recovery of the bricks. Stoppings when built should be placed in the middle of the X cut and well hitched in the floor and ribs.

The importance of air-tight stoppings cannot be too strongly emphasized.²² In a study of sixteen mines it was found that only from seven per cent to thirty-five per cent of the air was reaching the working faces, and that in one case a power savings of 49 KW per month was effected by repairing the stoppings and cutting down the amount of air

²¹ S. J. Craighead, "Efficient Coal Mine Ventilation," Explosives Engineer, 1934.

²² C. A. Herbert, "Some Factors Effecting Mine Ventilation," Indiana Coal Mining Institute, 1934.

TABLE IV

EFFICIENCY AND COST OF STOPPINGS

Type of Stoppings	First Cost	Strength	Tightness
Rough board lumber, 1-in. by 12-in.	1	9	7
Tongue and groove board lumber 1-in. by 12-in.	2	9	6
Concrete block, 8-in. by 16-in., laid in cement mortar ...	3	4	4
Hollow tile, 5-in. by 8-in. by 12-in., laid in cement mortar	4	5	5
Hard slate wall, 12-in. to 18-in. wide, plastered with cement mortar	5	6	2
Gob stopping, two 12-in to 18-in. boney or slate walls with 2-ft. core or refuse	6	7	8
Wall, 4-in. wide of double-size, vitrified brick, laid dry and plastered on one side, with pilaster	7	8	3
Wall, 8-in. wide of double-size, vitrified brick, laid in cement mortar, with pilaster	8	1	1
Wall, 4-in. wide of double-size, vitrified brick, laid in cement mortar, with pilaster	9	3	2
Wall, 8-in. thick of non-reinforced monolithic concrete	10	2	1

necessary to pass into the mine. It is possible if the stoppings are properly constructed to carry at least eighty per cent of the ventilating current to the working faces.

If such efficiency is to be secured, the use of doors must be reduced to a minimum, as it is not uncommon for a door to leak from four to five thousand feet of air into the return. Their construction depends largely on the type of service to which they will be put. They are usually built of lapped lumber, strongly braced and with long hinges to prevent sagging. In all ventilation-door construction it is very necessary that as complete a seal be made as possible. Large headers and door posts should be used and tightly fitted flaps used to prevent leaks. Air locks can be made by placing doors far enough apart to allow the length of a trip between them. Extra doors should be built that can be placed in service in case an accident causes the destruction of a regular ventilating door. Some companies also construct doors at inlet and returns of all working panels. Fastened securely open they are maintained there in case of fire when they can be closed and plastered with wood fiber quickly sealing the panel. The use of doors is one of the gravest hazards in mining today owing to the passing of the custom of having trapped at each important door. Where such doors are in use, some device should be developed that would give prompt warning if a door was left open too long or failed to close after the

passage of a motor trip.

Overcasts are used to conduct intake and return air currents across each other. Overcasts are most commonly used because of the tendency of undercasts to become filled with dirt or water. Overcasts should be built of fireproof material, the best ones being built of concrete or brick. A good method of construction is to build the wings and walls of reinforced concrete. Steel rails are then laid across the walls to form the overcast floor. Brick is laid between the rails and supported by the flanges of the rails. A coat of concrete is then poured over the tops of the brick and rails. The areas of the overcast should be as large as the airway leading to it; and the approaches, both floor and roof, should be sloped to cut down air resistance.

Air is divided and forced through the various splits in a coal mine by devices known as regulators. There are two forms in use, the box regulator and the regulator door. The box regulator consists of a solid board stopping or of a door with a hole cut in the center and provided with a shutter that can be slid over the opening so as to regulate the size of the opening through which the air is allowed to pass. Such a regulator should be placed at the outer end of the air course which it controls.

The door regulator is a door provided with a lock or chain so that it may be fastened at any position desired.

It is always placed at the mouth of an entry and is so arranged that it may be swung to one side or the other so as to increase the amount of air passing in the other entry. The area to be left open in a regulator may be calculated theoretically by the formula $A = \frac{.00040}{I}$, but in actual practice is secured by trial.

In small mines and in mines being developed, it is possible to conduct the air current around all the faces without dividing it; but as the mine grows larger, it is necessary to divide the mine workings into sections for purposes of ventilation. The state laws of Indiana provide that not more than seventy-five men be worked on any one split, and there are a number of other reasons for splitting an air current. The most important of these is that the mine is divided into separate districts, each of which has its own ventilating current. This in a gaseous mine reduces the danger of an explosion occurring in the mine because the air travels at less velocity, carries less dust, and is not as likely to form an explosive mixture as when the air is conducted in one continuous current. Should an explosion occur in one section of the mine, its effects would tend to be localized and not affect the workings on the other split.

The split system also reduces the functional resistance of the mine because the same quantity of air is circulated at greatly reduced velocity, and the mine resistance

varies as the square of that velocity.²³ Thus, for the same amount of rubbing surface in the mine, an air current traveling in two equal splits will meet with but one-fourth the resistance offered when the same volume of air is circulated in a single current. Since the mine resistance varies as the square of the velocity, the power will vary as the cube of the velocity taking the formula, $H = \frac{KSV^3}{33,000}$ and forming

a proportion $\frac{H_1}{H_2} = \frac{\frac{(KSV^3)_1}{33,000}}{\frac{(KSV^3)_2}{33,000}}$ and canceling all the

numbers that are the same, leaves $\frac{H_1}{H_2} = \frac{V_1^3}{V_2^3}$ or the first horse power is to the second horse power as the cube of the first velocity is to the cube of the second velocity.

For ease in figuring, let us imagine velocity of only two feet per minute produced by five horse power. Now suppose it is desired to increase this velocity to three feet a minute. Substituting these figures in the formula given, we should have 5 x as $(2)^3 : (3)^3$ or 5: x :: 8: 27; solving for x, we get 8 x 135 dividing by 8 would give x = 17 or more than three times the first horse power to produce its increase in velocity required. From this it can be seen that fast velocities in a mine are very expensive as well as dangerous.

²³ William J. Montgomery, "Theory and Practice of Mine Ventilation," Columbus, Ohio, Jeffrey Manufacturing Company, 1936, p. 285.

The limit of the desirable point in splitting the²⁴ air is reached when there is danger of reducing the velocity of the air too low. If it is reduced too much, the air in circulation will not sweep away the gases collected in holes in the roof and at working places. Methane at the face of an uphill room or blackdamp at the face of a dip or in a swag is difficult to move and requires considerable velocity of the air current. Under ordinary conditions the velocity of air passing working faces should not fall below three hundred feet per minute. In a mine generating gas, the velocity should be maintained at three or four hundred feet a minute depending on the quantity of gas given off at the face.

By the use of rock dust barriers and dusting, it is also easier to confine the force of an explosion to one air split. Many of the explosions in recent years have been checked in this manner, resulting in a great saving in life and property.

²⁴ "Coal Miners' Pocket Book," New York, N. Y., McGraw Hill Book Company, p. 918.

QUESTIONS FOR CHAPTER VI

1. What are stoppings and why are they used?
2. Why should wood, gob, and canvas be used for only temporary stoppings?
3. In what way does the presence of leaky stoppings affect the ventilation of a mine?
4. What is a line brattice and how should it be constructed?
5. What is the purpose of ventilating doors?
6. Why are doors in a mine objectionable?
7. When is the use of doors advisable?
8. On a main ventilating current, what provision should be made to prevent a short circuit while trips are passing through a door?
9. How should a door be hung?
10. Doors should be swung to close in what direction?
11. What is a regulator?
12. What is its purpose?
13. What types of regulators are used and where are they usually placed?
14. What is an overcast?
15. What is an undercast?
16. Why are overcasts preferable to undercasts?
17. How should overcasts be constructed?
18. What are the main requirements of an overcast?

19. What are some of the common errors in building overcasts?
20. How do overcasts aid haulage?
21. How do overcasts aid ventilation?
22. What is meant by splitting the air?
23. What is to be gained by splitting the air?
24. How does splitting aid in preventing explosions?
25. What determines the limit of splitting the air?
26. How does increasing the size of an entry affect the quantity of air that will pass?
27. How would this affect the power used?
28. How does increasing the speed of a fan increase the power used?
29. What is the benefit of decreased mine resistance when it is not necessary to increase the quantity of air in circulation?
30. For efficient ventilation what should be the minimum ventilation velocity?
31. For efficient ventilation what should be the maximum ventilation velocity?
32. As a general rule what should be the maximum ventilation pressure to secure efficient ventilation of the mine?
33. Why is a multiple entry system of development recommended?
34. On a blowing system of ventilation how may all mine seals be kept off the haulage roads?

35. Why is the use of booster fans in a mine objectionable?
36. What effect does the blowing system of ventilation have upon the omission of gas from old works and seals?
37. How does the mine resistance vary in respect to the ventilation?
38. Where should mine ventilation fans be installed?
39. Where should mine fans be located with respect to openings?
40. How is a mine fan installation protected from an explosion?
41. Why should mine fans not be located inside?
42. What are the common apparatus used by a mine foreman in measuring mine air?
43. How may a mine foreman determine from a fire boss's report whether the ventilation in a section is adequate?

CHAPTER VII

MINE MAPS

Lesson Subject:

Mine maps, their use, construction, and purpose for which they are made.

Points to be Studied:

Methods of reading mine maps, scales used, directions of ventilating current, nature of top as read from maps, methods of making sketches of mines, state laws in regard to mine maps.

Lesson Objective:

To become familiar with the methods, use, and purpose of mine maps and to be able to read and interpret them correctly.

CHAPTER VII

MINE MAPS

All maps are made and used as a pictorial representation on a small scale of the area they are drawn to represent, with symbols to represent the features they portray. In mining it is of utmost importance to make and maintain an accurate mine map showing all the airways, haulage, roads, traveling ways, rooms and other openings exactly as they exist in the mine. The map should show the thickness and character of the coal, the inclination and depth of the seam, and the elevations at different parts of the workings. It should also show the position of surface boundary lines, buildings, streams, bodies of water, roads and all such surface structures as might be affected by or affect the mine workings. The direction and manner of the ventilation current should be shown and the location of all ventilating equipment and passageways between the returns and fresh air intakes. The map should also show all prospect holes and drill holes with a key to the records of their logs.

If an accurate map of mine workings was not maintained, which showed the extent and exact location of the workings underground, with respect to surface property lines and other features, numerous difficulties could arise. The workings would be likely to cross property lines into coal that did

not belong to the company--giving rise to lawsuits and claims for damages. When special precautions need to be taken in driving under streams or roads, an accurate map is needed. If a mine is to be abandoned, a survey should be made showing the extent of the workings, as a knowledge of their location will be of utmost importance to any mines developed in that vicinity. Besides showing the relationship to surface workings, the map must show the relation to the various openings or workings in the mine to each other so as to avoid accidents caused by breaking into abandoned workings containing dangerous accumulations of gas or water.

Never is an accurate mine map perhaps appreciated so greatly as upon the opening of a long abandoned property. Such mines are usually flooded, and when new work is undertaken in connecting with works of an adjoining property or sinking a new shaft to be connected with the old works, the danger may be reduced to the minimum if the maps are accurate. Use of maps also promotes systematic workings and avoids the loss of much coal through squeezes by lack of proper pillars or failure to extract pillars at the proper points.

A good map, that shows the record of prospect holes and the thickness of the coal seam with the elevations of the coal at different points, also enables the operating force to plan the future development of the mine intelligently and to obtain the best haulage and drainage systems

possible. By scaling the map, it is possible to determine the distance between different points in the mine. This is useful as the work develops.

Making mine maps.²⁵ In making mine maps, a base is first established on the surface and its position secured by a tie to a government survey. A survey is then run from this base to the underground workings and all points in the mine are established by referring to the base. Lines are drawn east and west and north and south on the map from the base to use in locating the points to be placed on the map. Any distance east or west of the base is called the departure of the point to be established and any point north or south of the base is called the latitude. Any point may then be located by giving its latitude and departure and measuring them on the map.

Mine maps are made with different scales per inch. One inch on the map represents two hundred feet of the workings is usually used for complete maps of the mine, and one inch representing one hundred feet of the workings is used for small territories. The scale should be marked plainly on all maps, also the name of the mine, and its location as to county and state. The range and township in which it lies should be shown and also the section lines. The true north

²⁵ John Clayton Tracey, "Plane Surveying," New York, N. Y., John Wiley & Sons, 1907, p. 672.

should be marked on the map, and the name or names of the engineers making the surveys should be given.

Proposed plans of new works are usually drawn on mine maps as line drawings, a single line representing a proposed workings. The distances between proposed entries, between room centers, and other necessary information as to distances are given.

In the making of maps after the survey is made, the measurements secured are first "plotted" or drawn on a good paper with a cloth back. This is called a hard map. A tracing is then made, from this drawing, on a piece of linen cloth that has been made transparent by the use of chemicals. Each successive survey is placed on the hard map and on the tracing, and blue prints are made from the tracing whenever needed.

In making mine maps, a definite code of symbols has been adopted to designate different structures. It is desirable that these symbols be followed so that any one who becomes accustomed to one map will not be confused by a map showing different symbols. A definite system is also used in naming entries. The main entries off the bottom are usually called the Main North, Main South, Main East, or Main West by the direction they travel. Cross entries are numbered as they are turned and are numbered away from the bottom.

State laws. The state of Indiana has some specific laws as to the drawing and use of mine maps which read as follows. Section 2a, page 5, reads as follows:

Maps--Maps of Mine--Refusal--Inspector.²⁶

"Section 2. (A) The operator of each mine shall make or cause to be made, an accurate map or plan of the workings of such mine on a scale of not less than two hundred feet to one inch, showing the area mined or excavated, the arrangement of haulage roads, air courses, breakthroughs, brattices, air bridges, or overcasts, and floors used in directing the air currents in such mine, the location and connection with such excavation of the lines of all adjoining lands with the names of the owners of such land so far as known, marked on the map. Such map shall show a complete working of the mine, and, when completed, shall be certified to by the operator, agent or engineer making the survey or map to be a true and correct working map of said mine.

(B) The operator or agent shall deposit with the chief inspector of mines a true copy of such map within thirty days after the completion of the survey of the same, the date of which shall be shown on each copy, the original map and survey to be kept at the office of such mine open for inspection of all interested persons at all reasonable times. Such map and copy thereof, shall be extended each year between the first day of May and the first day of September, and shall be filed as required in making the original survey showing the exact workings of the mine at the date of the last survey.

(C) At the request of the operator of any coal mine, the owner of the land, the miners working therein or other persons interested in the workings of such mine, the chief inspector of mines shall make, or cause to be made, an accurate map of the workings thereof, on a scale of not less than two hundred feet to the inch, showing

²⁶ "Mining Laws of Indiana," Indianapolis, Indiana, Bureau of Mines and Mining, 1941, p. 5.

the area mined or excavated and the location and connections of the mines of all adjoining lands therewith, and the names of the owners of such lands so far as known. Such map shall be sworn to by the surveyor to be a correct map of the workings of such mine, and shall be kept on file in the office of the chief inspector of mines for examination at all times. All expenses shall be paid by the party causing such survey and map to be made. In case the operator of any mine shall fail or refuse to furnish a map as required by this law, it shall be the duty of the chief inspector of mines to appoint a competent mining engineer to make the survey and maps and file and deposit them as required by law, and for his service he shall be entitled to a reasonable fee to be paid by the party whose duty it was to make such survey and map, and shall be entitled to a lien on the mine and machinery to the same extent as is now provided by law for other work and labor performed in and about the mines of this state.

(D) Upon the payment of the fees, the chief inspector of mines shall make within a reasonable time, and deliver to the party so demanding the same, an accurate copy of any map or plan on file in his office.

(E) The original map or plan of any coal mine or the copy filed with the chief inspector of mines or a certified copy, issued under the hand and seal of such inspector, shall be evidence in any court of record in this state.

(F) In order that the maps, reports and other records, pertaining to the office of the chief inspector of mines may be properly preserved, a room shall be set aside and furnished in a suitable manner as an office for said inspector.

(G) It shall be obligatory upon the operators of adjoining coal properties to leave, or cause to be left a pillar of coal, fifteen feet in width on each side of the property line in each seam or vein of coal worked by them.

Mine Working--Map--Engineers and Land Surveyors.
All maps required to show the underground workings of any mine, within this state, shall be prepared

by a professional engineer or land surveyor, and shall be certified and sealed by such professional engineer or land surveyor. (Acts 1935, page 522).

Rights of Adjoining Land Owners.

Section 3. (A) The tenant or occupant of any land or lands on which a coal mine is opened and operated, the person or persons operating such mine, or the agent of any of them, shall permit any person or persons interested in or having title to any land or lands conterminous with the land or lands on which such mine is located, to have ingress and egress together with surveyors and assistants, into said mine, for the purpose of measuring, exploring and surveying such mine, for the purpose of ascertaining whether or not any coal has been, or is being mined and taken from the lands so owned by such person or persons; it being provided that such survey and measurements shall be made not oftener than once a month and shall be made at the expense of the party making such measurements or survey.

(B) Any land owner, tenant, occupant, agent, or mine operator, who shall refuse permission to permit such measurements, exploration or survey, as provided for above, shall forfeit the sum of one hundred dollars (\$100.00) for each refusal to the person so refused, which shall be collectible by suit in any court of competent jurisdiction in the state.

(C) If the owner of any conterminous land, or his agent, desires to make an examination, measurement or survey of any such mine or any part thereof situated and operated on adjoining lands, then the operator or superintendent of such mine shall, upon demand, provide every proper facility for making such survey with accuracy and safety to the owner of such conterminous land or to any surveyor or assistants who may make such examination or survey, by driving good air into, dangerous gases from, the part to be so examined and surveyed, and shall remove any obstructions that will prevent such survey, and shall provide any assistance if so called for by the surveyor, so that the encroachments, if any, on such conterminous lands may be clearly determined by such

examination or survey. Any person violating paragraph "C" of this section shall forfeit twenty dollars (\$20.00) a day for each day which he refuses to comply with such demand, which amount such conterminous owner may collect by suit in any court of the state.

Abandoned Workings--Mines--Fencing--Maps.

Section 4. (A) Before a mine or any part of a mine is abandoned, the owner or agent shall make a survey showing the farthest extremity of the workings of such mine, and a map thereof made and filed within thirty days thereafter at the office of the county recorder in the county where such mine is located; said map shall have attached thereto the affidavit of the mining engineer making the map, and of the mine boss in charge of the underground workings of said mine. Such map shall be properly labeled and filed by the recorder and preserved as a part of the records of the land on which said mine is located, and the recorder shall receive for said filing from said owner or agent a fee of fifty cents.

(B) The entrance of an abandoned mine shall be securely fenced off by the owner of said land on which said entrance is located, so that no injury can arise therefrom."

QUESTIONS FOR CHAPTER VII

1. What are the purposes for which a mine map is made?
2. What should a good mine map show?
3. Why should maps of areas to be sealed or mines to be abandoned be carefully prepared?
4. Of what value are accurate maps to a mine foreman or section boss?
5. Why should every man working in a mine be familiar with a map of the mine?
6. How is the direction of ventilating currents shown on a mine map?
7. What are the common scales used in making mine maps?
8. What should the title of a mine map show?
9. What knowledge of a mine may be gained by study of a mine map?
10. What is meant by the term, "hard map"?
11. Why are tracings and blue prints made of the hard map instead of taking it into the mine?
12. What is meant by the terms, latitude and departure?
13. If the scale of a map was three hundred feet to an inch, what distance would ten inches on the map illustrate?
14. How may distance between points be secured from a mine map?
15. Under the state law of Indiana, who is required to make

- a map or plan of the workings of the mines in the state?
16. What scale is required on these maps?
 17. What does the state law say must be shown on such a map?
 18. How often does the law require that a true copy of each mine be filed with the chief inspector?
 19. To comply with the state law, what must be done with the originals of the maps furnished the chief inspector?
 20. How may an owner of surface rights, a miner, or any person interested in the workings of a mine secure a map of the mine in which he is interested?
 21. Who makes such a map?
 22. Who pays for the cost of this map?
 23. Can an interested party secure a copy of any map on file in the chief inspector's office?
 24. What pillars does the state law require to be left on each side of property lines?
 25. Who has the authority to make mine maps and surveys in the state of Indiana?
 26. What does the law require of the owner of a mine or any part of a mine that is to be abandoned?
 27. What must be done with such a map?
 28. Whose affidavits must accompany this map?
 29. What are the requirements of the state law in regard to the opening of abandoned mines?

30. What are the requirements of the state law in regard to working places approaching abandoned workings?
31. On a piece of $8\frac{1}{2}$ x 11 paper make a sketch of the bottom of the mine in which you work.
32. On a piece of $8\frac{1}{2}$ x 11 paper make a line sketch of the mine in which you work showing main entries, cross entries, panels now working, hoisting and escape and air shafts. Make a complete title except scale.
33. On a piece of $8\frac{1}{2}$ x 11 paper make a line drawing of the haulage system of one working panel with which you are familiar.
34. On a piece of $8\frac{1}{2}$ x 11 paper make a line drawing of the ventilating system of your mine.

CHAPTER VIII

MINE FIRES

Lesson Subject:

Mine fires, causes, prevention, and extinction.

Points to be Studied:

Prevention of mine fires by safe practices, proper installation of electrical equipment, and good ventilation.

Extinguishing fires by direct fighting and by sealing.

Opening sealed areas after a fire.

Lesson Objective:

To develop the best methods for preventing fires and the best methods to be used in fighting, sealing, and unsealing fires.

CHAPTER VIII

MINE FIRES

Occurrence. Coal mines present and always will present grave potential fire hazards. The coal itself is combustible; in many mines there is a steady inflow of gas from the coal measures; wood is of necessity used in timbering; doors and brattices are built of wood; and inflammable substances such as explosives, oils and electrical installations are constantly used. Fires have occurred in all kinds of mines and from very different causes, causes so varied that it is difficult to classify and analyze them.

Every year hundreds of fires are started in the coal mines of the United States; but as they are promptly extinguished before they do any damage, no permanent record or report of them is made. This is particularly true of those mines which use black powder, are gassy, or are operated in coal that is subject to spontaneous combustion. In recent years, owing to mines being worked further in and the introduction of much electrical equipment, fires have tended to increase in number, although this has been offset somewhat by the decreased use of black powder.

As conditions exist today, the following classification will give the causes of mine fires about as the numbers occurs

by each cause:²⁷

- (1) Ignition of gas by electrical machinery, lights or shots.
- (2) Electrical shorts from power lines, trolley lines, bonds, or from faulty installations.
- (3) Use of black blasting powder.
- (4) Spontaneous gob fires.
- (5) Fires caused by explosions of gas or coal dust.
- (6) Fires caused by the heating of machinery.
- (7) Fires lighted in mines from surface fires.
- (8) Fires caused by lighting some combustible material by open lights, cigarette butts, blow torches, welding apparatus, and other unclassified causes.

The above classifications include nearly all the causes of coal mine fires and the number of their occurrence would follow in the same order. Two of the most serious accidents that have occurred in coal mine history have been due to a fire. One, at the Cherry Mine in Illinois, caused the death of two hundred ninety-seven men and the other, at the Alsdorp Mine in France, caused three hundred men to lose their lives.

²⁷ D. Harrington and W. J. Fene, "Coal Mine Explosions and Coal Mine Fires in the United States during the Fiscal Year Ending June 30, 1940," Washington, D. C., Department of the Interior, Information Circular 7136, p. 158.

Prevention. Considering the prevention of mine fires in the order named above, the best way of preventing a fire caused by the ignition of a body of gas by electricity, lights, or other causes is to prevent the accumulation of such bodies of gas. This may be done by ample ventilation, well conducted through all workings and by careful examinations to detect such occurrences. There are a good many ways that a body of gas may be ignited, and the sure prevention is to prevent the occurrence of such a body of gas.

Electrical shorts. The occurrence of fires due to electrical shorts may be prevented by the establishment of a good code of standards for electrical installation and a strict adherence to it. No insurance company would think of insuring a house that was wired as many of the coal mines today are wired; yet the hazard in a mine is as great as or greater than that of a building.

In installing underground wiring, all live wires should be supported by insulators and guarded as much as possible from danger of being dislodged by falls. All stationary equipment should be housed in fireproof vaults equipped with automatic fire doors and installed to comply with the mining laws of the state. All electrical equipment should be kept free from grease or dirt and regularly inspected for electrical defects. All defective or temporary splices should be re-spliced properly and if possible the splice should be

vulcanized. Insulated wiring should be used wherever possible and mounted on insulators, not nailed to a prop. Sectional switches should be set at short intervals and all power lines kept dead when not in use. Automatic circuit breakers should be used wherever possible and kept in a state of repair. M. G. sets and transformers wherever possible should be set on top and the power introduced into the mines through boreholes.

At all mines where electricity is used there should be a man in charge of the electrical equipment who is fitted by his ability, training, and experience to properly supervise the work. A systematic system of inspection should be made of all wiring and equipment monthly, and a copy furnished the mine foreman and superintendent. This report should definitely state the condition of each underground power station, of the conductors and controlling appliances of each main and branch power and lighting circuit, and of all motors and controlling appliances of each locomotive, mine machine, loading machine, pump hoist, or other piece of electrical equipment in the mine. Equipment and circuits found defective should be immediately removed from service until repaired. No voltages should be used or carried underground that exceed two hundred and seventy volts unless they are carried in metallic sheathed cables of which the sheath is grounded, and then only used for transformers or motors of which the high

voltage winding is part of the stationary equipment.

Use of black blasting powder. Black blasting powder yet remains the best explosive made for the production of lump coal, but owing to the occurrence of fires, explosions, and sickening or poisonous fumes in its use, it has to a great extent been replaced by the use of permissible explosives which are somewhat comparable to black powder in lump production. Fires due to the use of black powder may be caused by blown out or windy shots or by the powder setting fire to the coal itself as it burns. Wherever it is used, it is necessary to examine all places immediately after the shots are fired.

Spontaneous fires. Spontaneous fires are most likely to occur in lignite and subbituminous coal seams but do occur in all coal and are more prevalent in those seams that have a fairly high sulphur content. Clean loading and the loading out of all material that is likely to fire is the best prevention of such fires. Any coal that contains sulphur is very likely to catch if it becomes damp and is covered with gob or other material that will hold the heat until it reaches the point at which it begins to burn. In some mines, it is necessary to load all slack out as soon as cut, due to the tendency of the bug dust to heat and slack. Any gobbled material that is combustible should be watched and at any indication

of a rise in temperature should be loaded out. Oily rags or waste are also very likely to ignite spontaneously, and any accumulation of such material underground should not be allowed. Dirty waste in repair or machine shops should be kept in iron barrels and removed to the surface at short intervals.

Fires caused by explosives of gas or coal dust. Fires produced by these causes can be eliminated if accumulations of gas or coal dust are not allowed. Keeping the mine clean, the ventilation in good order, and rock dusting and sprinkling will reduce fires from this source to a minimum. There is a growing tendency to run water pipes to all working places and sprinkle the coal falls before they are loaded, thus eliminating the dust at its source. Leaky pit cars are also another source of dust and should be taken out of service at once and repaired if they are leaking coal.

Other causes. Fires caused by heating of bearings, by surface fires, and by lighting of combustible materials by open lights, blow torches, etc., are comparatively rare. Two of the worst fires in mine history were caused in this manner, the one at the Cherry Mine being caused by an oil torch setting a car of hay on fire; and a fire in France being caused by the setting off of a barrel of gasoline by an open light. Such fires may be reduced to a minimum by the use of

care and good sense and by using fireproof construction wherever possible. All surface building near the mine opening--especially fan and shaft bottom and slope entrances--should be of fireproof construction. Mine pump rooms, transformer rooms, motor pits, stables, and repair shops should be constructed of an incombustible material and equipped with automatic doors. Where it is necessary to store hay or oil underground, they should be kept in fireproof vaults, equipped with double doors that can be easily sealed. Electrical wiring around such structures should be very carefully inspected and no smoking allowed in these structures.

Fire fighting equipment. All surface structures around mine openings should be equipped with pipe or steam lines with ample outlets and accessible hose to be used in case of fire. These should be installed in such a manner that they will not freeze in winter. Good hose, frequently inspected, should be kept. If possible, water lines should be run underground with outlets at frequent intervals around the bottom, stables, shops, and any other places that a fire might occur. Fire extinguishers should be kept at all stationary power equipment, at the stables, bottom, and storage houses, and at least three should be kept in each panel when a loading unit is working. Barrels or sacks of rock dust should also be kept where they would be available in case of fire. Many mines maintain fire trucks which connect to a large tank with water,

pressure being furnished by the pressure of carbon dioxide gas which is generated through the action of sulphuric acid in sodium bicarbonate. This is mixed and expelled through a hose and is very effective in fighting mine fires. All other fire extinguishers that are kept in the mine should be of the carbon tetrachloride type that could be used on an electrical fire without harm. Besides the fire truck, another truck should be kept equipped with axes, picks, shovels, bars, and bushings and two hundred fifty feet of hose.

When a fire occurs. Anyone discovering a mine fire that he cannot put out at once should notify everyone within hearing distance and then go to the nearest telephone and notify the nearest boss, stating briefly the location of the fire and its size. The section foreman when notified should get word to the mine foreman. He in turn should immediately notify the superintendent, if the fire seems to be of a serious nature. The hoisting of coal should be stopped and the men should be notified to come out, if the location of the fire is such that it might endanger the men either by cutting off their escape or from the smoke of the fire. The surface fan should be left running normally unless the fire be directly at the foot of the downcast shaft. In that case, and that case only, it should be reversed. Emergency fire doors are maintained by some companies in order to quickly seal off

any working section in which a fire may start; but these should be closed only at the order of the mine foreman.

Methods of fighting fires. When a fire is discovered, it should be fought directly as long as it is safe to do so and there remains any chance to extinguish it by the means at hand. There is little danger in fighting an open fire if the proper safety precautions are taken. The return from the fire should be continually checked for CO, CO₂ and CH₄. The top in the vicinity of the fire should be closely watched as the heat from the fire will quickly affect it. There is not much chance of methane accumulating on the return side of the fire and backing up to the fire so long as part of the ventilating air is passing over the fire, as the fire itself will aid in the ventilation. While fires generate some combustible gases, there is little probability of an underground fire generating enough combustible gas to cause more than a slight explosion. The use of rock dust, chemical fire extinguishers, the loading out of gob fires, and water if it is available are all means by which a fire may be extinguished; but if the fire has progressed to a point where it cannot be controlled and put out by these means, either smothering by sealing off the area or by flooding must be resorted to. In the majority of instances, not enough water is available to effectively flood the mine in a short time and such a procedure is also costly, as the

mine once flooded will have to be pumped out and a great deal of damage to the entire mine will be done by the water itself. For these reasons, it is generally considered a better practice to seal a fire than to drown it.

Once sealing is decided upon, every safety precaution possible should be utilized. It is a matter of primary importance to have at every return from the fire, at all times, a competent man to test the returns in order that the men may be withdrawn if tests show that the gases are becoming dangerous. This testing should be done with a safety lamp, a methane detector, and a carbon monoxide detector. In a strictly non-gassy mine the hazards are chiefly from the carbon monoxide, although there is a slight explosion hazard in non-gassy sections, especially if water has been used in fighting the fire, which may have caused the generation of explosive gases. The hazards in sealing a fire in a gassy section are from carbon monoxide and methane explosions. As soon as the location of the seals are decided upon, the vicinity in which they are to be built should be heavily rock dusted and the dusting carried up as close to the fire as possible. While this is being done, material should be collected for the temporary seals.

Location of fire seals.²⁸ In the simplest examples of

²⁸ "Questions and Answers on Rescue and Recovery Operations Following Fires and Explosions," National Mine Rescue Association, 1938, p. 23.

gob fires, which must be sealed to extinguish them, the closer the seals may be set to the fire, the better the chance of quickly extinguishing the fire. The quicker the oxygen is brought below twelve per cent behind the seals, the less chance there is of an explosion and the closer the seals are to the fire, the smaller volume of the air. As a rule, the bigger the fire, the further away the seals are built, as the seals in any case should be far enough back to protect the men working on them in the event of a slight explosion.

In building the temporary seals, brattice boards and canvas are most commonly used. The purpose of building these seals is to cut off the air as quickly as possible. After the work is started, the structure does not need to be air-tight as the expansion of the heated air and gases will raise the pressure inside the sealed area and the leakage will be outward. In building the seals, no fixed rule has been established by the conditions surrounding each fire. If breathing apparatus is available, it is preferable to erect both the intake and the return stopping simultaneously. The principal object in sealing is to reduce the oxygen as quickly as possible and this can be done more quickly if both intake and return can be closed together. If this is not possible, the sealing can be done more rapidly by closing the intake first.

After the temporary seals are closed, all men should be withdrawn as quickly as possible from the mine for a period

of twenty-four hours and then permanent seals should be erected sealing off the area. These permanent seals should be well built of concrete or masonry and well notched in the roof and ribs. They should be built strong enough to withstand slight explosions and at least two pipes with valves, one at the top and one at the bottom, should be built in them. If the sealed area is to be recovered later, some provision should be made for a door or section in the center that could be removed.

Unsealing mine fires. Once the fire is sealed permanently, there should not be too much haste in unsealing it. Frequent air samples should be taken by means of chemical analysis and as long as there is any carbon monoxide back of the seals, it will indicate an active or recently active fire and no attempt should be made to unseal until it has disappeared. Because there may be other combustible gases such as hydrogen and methane behind the seals, it is essential that the oxygen be reduced to at least five per cent behind the sealed area, and it would be more desirable if it were reduced to one per cent.

Two methods are commonly used in unsealing a fire, by airlocks and by direct ventilation. Direct ventilation is the system most commonly used.

When a decision has been made to recover a sealed

area by direct ventilation, an airlock should preferably be constructed near the intake seal. A rescue crew using a life line and fully equipped for the work at hand breaks the seal, enters, observes conditions, takes temperature readings and air samples, and returns to the fresh air base. If the observations and examination of the affected region have shown that conditions are favorable, the return seal is broken by an apparatus crew; then the airlock is opened to admit air. The area is ventilated, but the combustible gases in the main return should, if feasible, be kept below the lowest explosive limit. If this method of recovering a fire area is employed, it is advisable that all men be out of the mine before the air is actually directed into the sealed area. Some automatic arrangement should be employed which would give sufficient time for all persons to reach the surface before the fire gases were actually moved. A reasonable period should be given for the fire gases to be removed and frequent determinations should be made of the return from the mine, and the time for any person to enter should be governed by the quality of the return air. This may be accomplished by installing a continuous methane recorder in the main return from the mine, by testing with an approved methane detector, or by systematic periodical sampling and analyzing on the portable Orsat apparatus. If the workings under seal are of an extensive nature, it will

probably be advisable for crews equipped with oxygen apparatus or possibly gas masks, to re-enter the mine and completely clear out the fire area of any standing fire gases.

QUESTIONS FOR CHAPTER VIII

1. Name some of the common sources of mine fires.
2. Discuss the installation of electrical equipment from the viewpoint of fire prevention.
3. Discuss what safety precautions could be used in the mines with which you are familiar for the prevention of mine fires.
4. What are the usual methods of fighting mine fires?
5. When should you decide to seal a fire area?
6. Which is the best method of fighting a mine fire, sealing or flooding?
7. What are the advantages of sealing a fire?
8. What are the disadvantages of flooding a mine fire?
9. What are the hazards in sealing a mine fire?
10. Should intake or return be sealed first or both together?
11. What distance should the seals be built from a fire?
12. Should temporary seals be used? Why?
13. How are temporary seals constructed?
14. Should permanent seals be built?
15. How should permanent seals be built?
16. What are the principal factors that govern the time for unsealing mine fires?
17. When is the atmosphere considered safe behind seals from the standpoint of explosions?

18. What does the presence of CO behind seals indicate?
19. What finally happens to the CO behind seals enclosing a fire area?
20. Describe the methods of unsealing a fire area.

CHAPTER IX

MINE EXPLOSIONS

Lesson Subject:

Causes and prevention of mine explosions.

Topics to be Studied:

Sources of explosions, types of explosions, causes of explosions, effects of explosions, and prevention of explosions.

Lesson Objective:

To learn the cause and prevention of mine explosions and the use of barricades to save lives after explosions.

CHAPTER IX

MINE EXPLOSIONS

Mining explosions are the most dreaded occurrence in the mining occupation, and any coal mine is a potential explosion hazard unless proper precautionary measures are taken. Today the source, cause, and prevention of mine explosions are well enough understood that if ordinary safety precautions are observed the occurrence of explosions can be almost entirely eliminated.

Mine explosions are originated from two sources, first, the accumulation of bodies of gas and, second, the accumulation or depositing on the surface of mine workings of fine coal dust in explosive quantities. If either of these conditions exists in a mine, there is a potential explosion present waiting for a chance to happen. When as serious occurrences as mine explosions can be narrowed down to two causes, it would seem that they could be easily prevented. Yet explosions have taken and still are taking their annual toll of lives. Table V shows the occurrence of explosions by states in the United States from the first year of which records were available up to and including 1935.

The first column gives the total number of explosions; the second the average number of explosions per year; the third the total deaths due to explosions; and the fourth the

TABLE V

OCCURRENCE OF MINE EXPLOSIONS, 1883-1935²⁹

State	Period	Ignition or Ex- plosions	Average Number of Explo- sions per year	Deaths Due to Explo- sions	Average Number Deaths per Ex- plosion
Colorado	1883-1935	120	2.3	798	6.65
Illinois	1883-1935	281	5.4	818	2.91
Indiana	1878-1935	182	3.2	397	2.18
Kentucky	1884-1935	77	1.51	368	4.78
New Mexico	1895-1935	18	.45	492	27.30
Pennsylvania					
Anthracite	1870-1935	1268	19.5	2236	1.76
Bituminous	1870-1935	178	2.74	1997	11.21
Utah	1900-1935	12	.34	408	30.40
Virginia	1839-1935	34	.35	551	16.22
West Virginia	1883-1935	298	5.73	2077	6.96
Wyoming	1881-1935	69	1.28	534	7.74

²⁹ D. Harrington, "Progress in Safety in Coal Mining in the United States," Washington, D. C., Department of the Interior, Information Circular 6810.

average number of deaths per explosion. There has been in the past ten years in the United States as a whole a decrease in the death rate per explosion and also a little decrease in the number of explosions per year, but they occur too frequently. The occurrence of any explosion is no longer justifiable with the present-day knowledge of their prevention.

The most common cause of the ignition of explosives in the past years was the use of black powder in solid shooting with the frequent occurrence of windy shots causing dust explosions or the lighting of both gas and dust. This occurrence in recent years has been greatly reduced through the introduction of permissible powder, so that today explosions due to the use of black powder are comparatively rare. Today the most common causes of ignition are electrical flashes, faulty electrical equipment, open lights, and other sources of flame. Occasionally the occurrence of a body of gas is unavoidable but these are rare. When such a body of gas does occur and is ignited, the explosion can be localized by the present-day methods of air splitting and by the use of rock dust and rock dust barriers. In the past explosions that have occurred, some of the common causes of the presence of the gas have been accumulation of gas through inadequate ventilation, accumulations of gas in squeezing areas, with a resulting interruption of the ventilating current, improper ventilation and inspection of abandoned areas, liberation of gas through

improperly constructed seals, stoppage of ventilating current by falls in air courses, destruction of doors through accidents, doors left open by accident or carelessness, failure to comply with the law in driving cross cuts, use of booster fans, cutting and shooting into old works not properly located, failure to seal off old works when abandoned, liberation of gas through destruction of pillars by squeezing, lack of mine discipline and disregard of the provisions of the state mining laws, and failure to enforce mine rules and regulations.

Phenomena of mine explosions.³⁰ --Definition. A mine explosion is usually understood as meaning that violent disturbance of the atmosphere within a mine which is caused by rapid combustion of explosions of gas or coal dust or both and which produces a destructive blast of air that is accompanied by flame.

A gas explosion, in this discussion, will mean combustion of gas accumulations where found in a mine with results as mentioned.

A coal dust explosion will mean the rapid combustion of coal dust (although there is always some gas present during such combustion) when raised in a cloud inside of a mine.

³⁰ Bureau of Mines, Information Circulars No. 6710, 6752, 6753, 6760, 6764, 6765, 6801, 6802, 6819, 6870, and Bulletins 56, 167, and 369.

Gas explosions. When an explosive gas mixture is placed in a tube closed at one end, and the mixture is ignited at the closed end by some source of heat, the flame of the burning gas will travel with rapidly increasing velocity toward the open end. The process whereby the gas is ignited is as follows: If the heat supplied by the ignition source is small, the gas in immediate contact with this ignition source may be burned but the amount of heat generated is not sufficient to cause ignition of the unburned gas which envelops the burning gas; however, if the source of ignition has sufficient heat to raise the thin section of gas which surrounds the flame above its ignition point, then the heat from the combustion will be sufficient to ignite the next adjoining section of gas and the flame of combustion will pass through the gas mixture in this manner with increasing velocity.

The velocity which a gas-explosion flame will attain depends on the nature of the passage, the type of gas mixture, and other conditions. In a hydrogen-oxygen mixture, for instance, the flame starts its travel slowly, as in all gas explosions, but soon reaches a point where the velocity exceeds that of sound. At this point the flame travels so rapidly that one expert has used the term "detonation" to describe the explosion, since the same type of combustion takes place when a detonator is struck. The flame travels with the velocity of sound in the burning gas, which itself is moving rapidly

forward en masse, so the explosion flame travels faster than the velocity of sound. In this type of explosion each section of gas is compressed so suddenly by the pressure due to the sudden expansion of the burning gases that the temperature is raised above the ignition point of the gas which suddenly ignites.

It is hardly probable that gas explosions in mines will experience the detonation wave or flame described above. Most gas ignitions result in low-velocity flames which quickly consume all of the available gas and die out, spreading destruction only in the immediate vicinity of the ignition but producing poisonous gases that affect workmen outside of the explosion area.

Dust explosions. There is considerable similarity between gas and dust explosions. The gas explosion requires a mixture of the gas with air in certain proportions; the dust explosion requires "intimate" mixture of the coal dust and air in "certain" proportions or the dust must be raised in a cloud. Both explosions require a certain amount of heat in the ignition source to start the initial combustion; any lesser amount will fall short of igniting the gas or dust and no explosion will occur. After initial ignition, the heat generated by combustion of the dust must ignite an adjoining section of dust, and in this manner the flame will travel through the

dust cloud with increasing velocity.

When coal dust is burned, the gases produced will occupy considerable more space than the original air and dust mixture owing to the high temperature developed; since the gases are more or less confined by the mine passageway, considerable pressure is developed. This pressure will cause a flow of air from the point of high pressure to a point of lower pressure and this causes the destructive wind or "pressure wave" which accompanies dust (and gas) explosions. This pressure wave usually precedes the wave of flame and thus aids combustion by raising coal dust into a cloud which is burned by the following flame wave. It can be seen, then, that a coal dust explosion under favorable conditions will progress through a mine as long as there is coal dust to feed the flame.

Shock and pressure waves. In dealing with "shock" or "pressure" waves we must divide them into two classes, those which are the result of the concussion which originates the explosion, and those which are the result of the explosion itself.

A blown-out shot or a fall of roof will produce a concussion which spreads through the air with the velocity of sound. It is this pressure wave that gives us the sound of a shot or fall. This velocity will depend on the density of the air and will differ in mines having different elevations

and temperatures. Blown-out shots have the power to raise coal dust into a cloud near the point of the shot, but the pressure of this shock wave diminishes as it travels away from this point; it is doubtful, then, if this shock wave could raise dust except in the immediate vicinity of the shot. The same is true of falls of the roof, although the shock wave originated from such a cause can have sufficient pressure to raise dust clouds at a considerable distance away if the fall is a heavy one. The wrecking of a trip of cars will produce a small shock wave, while an explosion of gas will have a shock wave of an intensity which will depend on the quantity and quality of the gas-air mixture. Any agency in the mine which is capable of raising a dust cloud will produce an initial shock wave.

If ignition of the dust cloud follows the initial shock wave, there is a rapid succession of pressure waves produced by the successive explosive combustions of the dust and accompanied by a forward movement of the column of air. These pressure waves and forward movements continue as far as the coal dust explosion propagates, stirring up the dust ahead of the flame. It is this forward movement with its accompanying waves raising coal dust that makes spread of a coal dust explosion possible.

Flame velocities and temperatures. Although shock

waves may have velocities in excess of 1,100 feet per second, the initial flame velocity in a coal dust explosion will rarely exceed 500 feet per second. The flame velocity depends on the rate at which combustion can proceed through the dust cloud present, and also on the movement of the air carrying the dust cloud along the passageway. If conditions are favorable, the flame may slow down and die out. The lowest flame velocity recorded by the Bureau of Mines in experiments in a self-sustained dust explosion was 30 feet per second (20 miles per hour approximately). Under favorable conditions for propagation the flame velocity will increase from this initial velocity, or will accelerate, until velocities of 1,000 to 1,500 feet per second may be attained in one second of time or less. The maximum velocity attainable is in doubt but velocities in excess of 3,000 feet per second (2,040 miles per hour) have occurred in the Experimental Mine of the Bureau of Mines, and 6,000 feet per second has been indicated. The possible experimental errors at such high velocities become so large that there is considerable uncertainty concerning them. A velocity of 6,000 feet per second is much faster than black powder burns and it approaches the velocity of detonation of some of the slower detonating explosives. At any velocity in excess of 1,200 feet per second (which is the approximate velocity of the pressure waves) the flame can overtake the initial shock wave if a sufficient length of passageway is

available, and will then proceed through a dust cloud formed at its front by the pressure of the expanding gases of combustion, projecting its own waves far enough ahead to stir up the amount of coal dust necessary for propagation of the explosion.

Attempts at measuring the temperatures of explosions have not been very successful. Foils of various metals which melt at different temperatures have been used and temperatures of approximately 2150° F. on one occasion were thus obtained. It is questionable, however, whether the fusing of the foil was produced by a temperature of slightly more than 2150° F. during a comparatively long exposure, or whether a much higher temperature melted the foil during a short exposure. The consensus of opinion is that temperatures between 1250° F. and 2150° F. are obtained during an explosion. Attempts at calculating temperatures theoretically indicate that 5000° F. would be attained as a maximum, yet the observed temperatures are less than half this value.

Shape of flame. The flame of a coal dust explosion in a mine passageway has a pointed shape with the point somewhere near the center of the passageway. No doubt the outline of this shape changes from second to second, but the general pointed shape is retained. In a weak, slow explosion the shape will have sharp point and the combustion flame may not extend entirely to the walls. In fact, tests have shown that

in weak explosions the zone of combustion is confined well to the center of the entry and at times may not extend as far as a point midway between the center and the rib of the entry. Experiments have indicated that the length of point may be as much as one hundred feet and the flame length, including the point, may be three hundred feet long at any one instant. With an increase in flame velocity we find the point becomes more blunt and the total length of flame becomes less; lengths as low as fifty feet have been indicated. The duration of a flame, the time that it requires to pass a given point, ranges from 0.03 to 0.1 of a second.

Pressures produced by coal dust explosions. The pressures produced by burning coal dust during first ignition are low and usually not more than three to five pounds per square inch above atmospheric pressure. An unusually strong ignition source may increase this initial pressure. If conditions for propagation are unfavorable, so that a slow, weak explosion results, the pressures developed may never rise above the initial pressure. If conditions are favorable for propagation, the pressures developed will rise rapidly and will reach from twenty-five to fifty pounds per square inch within a second. Under very favorable conditions these pressures may reach sixty to seventy pounds.

The pressures developed during combustion of coal dust

cannot be calculated in the present state of our knowledge of the physical laws involved. Theoretically, the maximum pressure obtainable at atmospheric pressure is one hundred and forty-two pounds per square inch; however, as the explosion develops, precompression of the air occurs ahead which may be several atmospheres of pressure. Thus, if there is sufficient coal dust present, the pressure of the explosion is correspondingly increased and extreme violence may result. It is characteristic of explosions in dusty coal mines unprotected by rock dusting that the violence of the explosion increases as it travels. On the other hand, if the flame is extinguished by rock dusting or by other means, the pressure rapidly drops.

Tests in the Experimental Mine of the Bureau of Mines produced a maximum pressure in one instance of one hundred and twenty-seven pounds per square inch. Higher pressures were experienced but wrecking of the manometers prevented the obtaining of records. High pressures are of shorter duration than low pressures; thus pressures of fifty pounds per square inch last only a few hundredths of a second and approximate a hammer blow.

Chemical reactions occurring in a coal dust explosion.

In slow or weak explosions, a thin layer of relatively pure air is found to remain close to the rib, probably filled with a dense layer of suspended dust, until after the flame has

passed. At the same time in the center of the entry the oxygen content of the air has been reduced to not over two or three per cent; while from ten to twelve per cent CO_2 and appreciable quantities of CO and other distillation products are formed from the coal dust.

In rapid and violent explosions of dry dust the combustion removes more oxygen so that its content in the entire body of air may be less than one per cent. CO may be formed in quantities of four per cent or more, and CO_2 will be reduced at the same time. Evidently the CO is formed by the action of extremely hot carbon on CO_2 after primary combustion has taken place. The coal dust is also distilled by the higher temperatures and more prolonged heating so that hydrogen and methane are formed in appreciable quantities. At times appreciable quantities of methane and unsaturated hydrocarbons are found.

If the coal dust taking part in the explosion is wet or damp, a reaction similar to that used in forming water gas is present; as a result, large quantities of carbon monoxide and hydrogen are formed. One sample of gases taken under such conditions contained 0.8 per cent O_2 , and 11.7 per cent CO_2 , 6.2 per cent H_2 , CH_4 , and C_2H_6 .

After the flame has passed, the chemical reaction ceases. Changes in composition are then caused by dilution with fresh air from outside the explosion area, and also by absorption

of some of the gases by the coal dust or coal ribs. In any event, the gases will undoubtedly be unsafe to breathe until full ventilation has been restored.

Coking phenomena. Coke found after coal dust explosions in mines is the residue of partly consumed dust. The quantity of coke found after an explosion depends largely on the coking properties of the coal in the mine. Other conditions being equal, a slow explosion will produce more coke because the dust is exposed to the heat of flame for a longer period of time and there is less tendency to destroy the coke by violence.

Although there is no definite relation between coke deposits and the origin of an explosion, it has been found that the coked dust near the origin usually faces the source of explosion. As the explosion accelerates, the coke is more likely to be found on timbers on the opposite side from the source, and as the explosion dies away the coke is again found on the facing side of projections.

Much less coke is found after a violent explosion than after a weak explosion. This may be due to more complete combustion, or to the fact that masses of coke are broken up by the subsequent violence.

Movement of objects by an explosion. In the section of "shock" and "pressure" waves we did not attempt a discussion of all the pressure waves set up by the combustion of coal dust.

It is known that the pressure waves, of which there are many, are caused by the rapid combustion of coal dust with a certain zone, which zone is moving with a velocity that exceeds that of sound. When the explosion is traveling freely along a passageway and is not dying out, the pressure in the flame produced by the intense heat is greater than that ahead or behind it. Because of this, a horizontal column of air is forced ahead of the advancing combustion zone at high velocity, and likewise, a column of burned gas is propelled backwards toward the origin of the explosion.

The variation in pressure waves and their effect on objects in the explosion area is extremely interesting. If the pressure waves in advance of the flame zone are strong enough to move objects, their travel in this direction will continue until they are overtaken by the flame zone and they come under the influence of the backward or "retonation" waves. Quite often these latter waves are of much greater pressure than those which first moved the object so that its movement back toward the origin of the explosion may be even more violent than the original motion. If the explosion continues forcefully, the object may come to rest much closer to the explosion origin than it was originally. Instances of this happening to heavy boards and mine cars are definitely known.

After an explosion is extinguished, there is an inrush of fresh air to fill the partial vacuum created by cooling of

the hot gases. This inrush may carry light objects for considerable distances and complicate the evidence of movements of materials. The position of objects, therefore, cannot always be relied on to point the way to the origin of an explosion. Final movements of objects may be away as well as toward the origin, and a careful study involving all factors is necessary in determining the exact location of the ignition.

Character of the initial ignition impulse. The manner in which an explosive mixture of gases is ignited, or the character of the initial ignition impulse, is a factor in gas explosions. It was not uncommon for miners in this country twenty to thirty years ago to burn out accumulations of gas in the working places by raising a lamp or candle to the roof where the gas had accumulated and ignite the gas by this means. A firedamp mixture may be ignited by a lamp flame or some other source of quiet ignition without causing an explosion; but the same mixture, when fired by a blown-out shot, may explode with violence. The volume and intensity of the ignition source are the factors that determine in many cases whether quiet burning or an explosion will result.

The volume of the flame source is important. A large volume will communicate considerable heat to the explosive mixture and thus cause easier ignition throughout the gas mass. A large quantity of initial heat will overcome the losses due to conduction, convection, and radiation and still allow

sufficient heat to cause rapid ignition of the gas.

The intensity of the initial impulse or the temperature of the igniting flame will likewise determine whether quiet burning or an explosion will result. The heat transferred from the ignition source to the gas and the heat developed by the initial burning is dissipated so rapidly under normal conditions of temperature that it is necessary to conserve this heat if an explosion is to result. Thus, a higher initial temperature, such as would be obtained from electric arcs, will often cause explosions; whereas an ignition source of lesser intensity would not cause an ignition.

Coal dust explosions.³¹ Practically all operations in coal mining are accomplished by a production of fine dust, and it has only been in recent years that the part played in mine explosions by coal dust has been recognized. Fine dust once accumulated may be thrown in the air and ignited by a smaller gas explosion, or it may be thrown in suspension by some other shock and then ignited by electric arcs or open lights. Once the explosion is started, the pressure wave aids the explosion by raising the coal dust ahead of the flame.

The finer the dust is the more explosive it is and the presence of coal dust will bring the lower explosive limit

³¹ United States Bureau of Mines, Washington, D. C., Bulletins 56, 167, and 369.

of methane down to one and one-half per cent. The dust found on ribs and roof is also more dangerous owing to its fineness. Only a small amount of this dust is needed to start an explosion, as tests have shown that ten pounds of dust, if present in a cloud such as might be formed by a wreck or by a heavy fall, could be ignited by an electric arc or by an open light.

Prevention of coal dust explosions--causes and remedies.

The lessening of coal dust explosion hazards must take into consideration the means of producing coal dust and the means whereby such production can be diminished.

(A) Coal dust is produced at the face by undercutting (or machine cutting of the coal face), blasting, and loading operations. The remedies to be employed include use of a water spray on the cutter bar, using the face and coal before blasting and during loading operations.

(B) Coal dust is produced by pieces falling off the overloaded mine cars or through cracks in the bottom and ends of cars and being ground underfoot and by car wheels. The remedy is to have cars with tight ends and high sides, and not to load above the sides. Tight-end cars will require revolving dumps.

(C) Coal dust is produced when coal sloughs off the roof or ribs along haulage or traveling ways and is ground to dust under haulage equipment and under the many feet of men

and animals. The remedy is difficult, since it involves timbering and tight lagging at the ribs or lining the passageway with brick or concrete, or coating it with cement by the gunite process.

(D) Coal dust is formed wherever coal is dumped, as at shaft bottom dumping points or into the mine workings by the ventilating current. The remedy, of course, is to eliminate dumping coal inside the mine and to move preparation plants away from the point where the intake air enters the mine.

Wetting coal dust. Humidifying the air current at one time was considered an effective means of wetting coal dust. Tests have shown that the moisture content of pure coal dust remains practically the same in a saturated air current and that the dust takes up additional moisture only in supersaturated air. This means that the mine air must be foggy in order to wet the coal dust, and this condition would be extremely undesirable in mines. Even where such a method would be allowable, it would be necessary to give additional sprinkling to the dry places.

Use of calcium chloride has been tried commercially, but was too costly for the results obtained. This salt has the property of taking moisture from the air wherever it is exposed, and the use of such a salt would, theoretically, moisten any coal dust coming in contact with it. It was found

that water did collect in globules and films on the surface of the coal dust where the calcium chloride had been applied, but the dust underneath the surface was quite dry. Even when thoroughly mixed with the coal dust, this salt did not effectively wet the coal dust. If effective wetting could be obtained on the floor of passageways by thorough mixing by the feet of passersby, the calcium chloride would still have to be added to the rib and timber dusts with the possibility of ineffective wetting of these dusts existing.

Use of a water sprayer on the coal dust by means of tank cars and hose, pipe lines and hose, and by fixed water sprinklers has also been made at various times. In order to wet the pure, fine coal dust effectively, water must be added until it represents thirty per cent by weight of the dust and in this condition the coal dust would resemble mud. It is obvious that even elaborate wetting devices are useless if the coal is not effectively dampened, and the nature of coal dust is such that effective dampening requires much labor and equipment and thus is a costly procedure.

Wetting mixtures of coal dust and rock dust appear to be more effective in actually dampening the coal dust than when it is sprinkled alone. The ease of wetting appears to be somewhat in proportion to the percentage of shale or rock dust present and may offer a solution to the difficult problem of wetting coal dust where such is necessary.

Dustless zones. The idea of a dustless zone as a means of preventing the spread of a gas or coal dust explosion has been tried out by actual test. The so-called dustless zones were cleaned by sweeping them with brooms and by blowing with compressed air jets. Notwithstanding the practically dustless conditions obtained, an explosion of coal dust which was started in a zone of three hundred feet in length had sufficient force for its flame to travel eight hundred feet through the dustless zone; and second explosion, originated in one hundred feet of an entry well covered with coal dust, had sufficient force to travel five hundred feet through the dustless zone. The danger of explosions propagating to great distances cannot be wholly eliminated by any method whereby only the coal dust is removed. Some method whereby the explosion, once started, can be limited must also be provided.

Knocking out weak stoppings. It has been advocated that the use of weak stoppings which would blow out and relieve the initial pressure of an explosion, thereby allowing the flame of the explosion to die out, would aid in preventing the propagation of explosions. Tests have shown that there are many instances in which the blowing out of a stopping after an explosion was well started did not prevent the continuance of the explosion. Seemingly the only time when explosions failed to propagate was when crosscuts at the scene of the

explosion were open, which would approximate having weak and easily knocked out stoppings in these same crosscuts. The relief offered by weak stoppings is of doubtful value, while their disadvantages include the fact that they are leaky, and also that after an explosion every stopping would have to be restored before ventilation would be possible. Substantially built stoppings of concrete, masonry, or other non-combustible materials have withstood explosions of considerable force and thereby made the task of recovering the mine much easier.

Application of rock dust. The Bureau of Mines determined in 1913 that the application of incombustible dust, commonly called rock dust, to explosive coal dust would absolutely prevent ignition or would stop the propagation of an explosion if present in sufficient quantities. It is now generally accepted that rock dust, if fifty-five per cent or more of the total dust content, will prevent or stop explosions, although the presence of explosive gas requires the addition of between two and ten per cent more rock dust for each one per cent of gas. These values indicate the average for bituminous coal mines, and each mine will present its own particular problem in dust application.

Summary of methods for preventing explosions. The absolute prevention or limitation of mine explosions, either of gas or coal dust, will rarely result from haphazard methods

of removal of hazards, but will be the result only of a definite plan of procedure for the elimination of gas and dust hazards from the time the coal mine is opened and made ready for production.

The development of the mine should be planned with the idea of having a sufficient number of airways and haulageways to provide for adequate ventilation. A coal seam which gives off considerable gas or is extremely friable and liable to produce fine sizes of coal dust should be treated as much more dangerous than a non-gassy, harder coal seam. Openings into the mine should be of ample size and sufficient number to meet any emergency.

Ventilating equipment and devices should be of a permanent nature. The fan or fans should have ample ventilating capacity. The necessary stoppings should be substantially built of non-combustible material (except temporary stoppings), and doors should be replaced with well built overcasts whenever such is possible.

The mine should be developed on an approved plan which will separate the mine into districts so that ventilation can be properly controlled. Adequate ventilation should be provided. That is, all open parts of the mine should be ventilated by a column of air which will not only "dilute, render harmless, and remove" gas but will also be sufficient to "render harmless" any sudden outburst of gas. Doors should be

eliminated wherever possible, and all abandoned areas should be sealed effectively.

Inspection must be conscientious, inflexible and rigid, and should be followed in a well planned procedure. Inspectors should be competent. Searching employees for smoker's articles should be a regular duty.

Supervision, by which is meant the origination and maintenance of proper inspection, ventilation, equipment, and safety measures, must be a part of a well planned "prevention of explosions" campaign.

The dust resulting from mining operations should be controlled by watering or rock dusting. Watering should be done at the points where dust is made, i.e., at the face during cutting and blasting, on the coal while loading is done, and on the tops of loaded cars before they are moved. Sprinkling of haulage roads is a valuable method of allaying dust. Rock dusting in all mines, except anthracite mines, should be done wherever possible, and use should be made of rock dust barriers at the entrance to working sections. The removal (loading out) of excessive coal dust is recommended also.

Blasting should be done by competent shot firers. Only permissible explosives should be used. Where it is possible to undercut the coal, it should also be sheared to minimize the danger attendant on blasting.

Erection of barricades after mine explosions.³² After mine explosions or during mine fires, deadly gases are generally found throughout the workings and imperil the men who survive the violence or heat. Five hundred and fifty-five men in America alone have saved their lives by building barricades or bulkheads to protect themselves from the deadly gases, and many men have lost their lives by neglecting to build barricades. Also, imprisoned miners have built barricades in an imperfect or inadequate way and as a result have perished. A barricade must be gas-tight, and the barricaded place must not have any other connection and must not have been contaminated by gas before use as a refuge.

Investigations after mine explosions have shown that many of the men found dead had escaped the violence and flame of the explosion but had succumbed to the afterdamp left by the explosion. The evidence collected shows that in a selected list of 140 mine disasters 1,477 men were killed outright and 1,391 men were overcome by afterdamp. In other words, about forty-eight per cent of the men killed in these disasters were alive after the explosion occurred and probably died from afterdamp.

In some instances, miners have traveled long distances

³² D. Harrington and M. W. Bunewitz, "Saving of Life by Barricading in Mines and Tunnels at Times of Disaster, " Washington, D. C., United States Bureau of Mines, 1933.

from their working places before encountering deadly gases, and groups of men have been found dead in remote sections of mines to which they had retreated to escape the afterdamp. Again, men have been found dead near a pile of brattice material, which they did not use because they probably did not know that a barricade would be of value. In several instances where miners were rescued after an explosion, they said that they knew nothing about erection of barricades, so there are possibly many others unaware of this method of escaping death when left alive in a mine during a fire or after an explosion.

When there is a fire or an explosion in a mine, undoubtedly the first impulse of the survivors is to dash for the nearest exit, either to the surface or to the shaft bottom to be hoisted out of the mine. Under circumstances such as these, men naturally desire to get out as quickly as possible but frequently, in making their way to the surface, they rush into afterdamp or the afterdamp overtakes them and they are overcome. In every crowd there is nearly always at least one cool-headed man who is able to take charge of a number of excited and more terror-stricken men, and he should be obeyed for the welfare of all concerned. When miners are trapped by a mine fire or left alive after an explosion, they should not rush aimlessly around but should immediately make an effort to protect themselves. The following recommendations are made as an aid to the proper method of doing this:

Recommendations for construction of barricades.

- (A) When entrapped by gases from mine fires or explosions, keep uppermost the thought of building a barricade or bulkhead and collect tools, timber, canvas, water, dinner buckets, and everything else that might be useful.
- (B) A suitable place should be chosen as soon as possible for the erection of a barricade and its construction should be started without delay as the deadly gases often travel quickly. An efficient barricade can be erected in periods from thirty minutes to two hours, depending upon conditions.
- (C) The ventilation should be short-circuited as soon as possible by opening doors or destroying stoppings and temporary barricades should be erected by hanging brattice cloth or moving a door to a new place across the entry. The permanent barricade should be started about fifty feet from the temporary construction.
- (D) As much territory as possible, such as entries or drifts, rooms, and crosscuts, should be included in the barricaded areas, regardless of the number of men in the party, so as to provide a maximum quantity of air.

- (E) Before constructing barricades, make sure that there are no other openings or connections with other workings through which gases could enter. Also, make sure that the entry or drift is not in broken ground or in strata through which gases could enter. In metal mines, back-filled ground should not be chosen since gases are likely to pass through such regions.
- (F) If a barricade of lumps of coal, slate, rock, or ore is erected, two walls about two to three feet apart should be built and the space between should be filled with fine material, preferably mud. The stoppings must be air-tight. Board stoppings are, as a rule, not as easily made gas-tight as those erected of dirt or rock and dirt, especially dirt in the form of soft clay or mud. Board stoppings covered by canvas or damp brattice cloth can be made sufficiently tight to exclude the dangerous gases.
- (G) All chinks and holes in the barricade should be stopped with clay, rags, clothes, or similar material.
- (H) Barricades in coal mines should not, if avoidable, be erected in workings or places that give off gas (methane), for firedamp may accumulate and be ignited in some way. Also the accumulations of

methane will displace air behind the barricades, and the life-sustaining capacity of the barricaded area will be shortened.

- (I) If a piece of pipe is available, it should be placed through a stopping of the barricade and plugged at the inner end so that tests of air outside of the barricade can be made.
- (J) After the barricade has been built, the men should keep as quiet as possible because a man uses several times as much oxygen when he exerts himself as when he keeps absolutely quiet.
- (K) All flame lamps should be extinguished to conserve oxygen; also, if methane is given off, the flame would soon cause an explosion. It is desirable not to use candles, carbide lamps, flame lamps, or electric batteries needlessly.
- (L) Food and water should be conserved as long as possible.
- (M) A sign should be placed outside the first stopping, if more than one is built, to show that men are behind it.
- (N) If possible, barricades or bulkheads should be erected with a valve enclosed in the compressed-air line, if compressed air is used in the mine. The valve should be opened when necessary to

furnish additional air, precautions being taken, however, not to allow poisonous gases to enter the barricaded region through the compressed-air line after the compressed air fails.

- (O) It is very important that underground employees should be familiar with all escapeways, manways, and other exits. They should also know which entries serve for intake and return air currents. A mining company should have all parts of a mine equipped with easily-read direction signs indicating the pathway to exits.
- (P) Many lives have been sacrificed because miners did not know the coursing of the ventilation in the particular section of the mine in which they were at work at the time of an explosion or fire.

Life-sustaining capacity of barricaded chambers.³³

A barricaded area forms a refuge chamber for the men within, and the cubic content of the enclosed space determines the number of men and length of time they can safely remain there. In breathing, the men consume oxygen from the air and give off an almost equal amount of carbon dioxide. When the proportion of carbon dioxide in the air of the enclosed space reaches

³³ "Erection of Barricades after Explosions," Bulletin No. 35, Washington, D. C., Superintendent of Documents, 1931.

eight per cent, the men will breathe heavily and be at the point of complete exhaustion. Actually, men have lived for considerable periods in an atmosphere in which a carbide light would not burn, indicating that the air they breathed had less than twelve per cent of oxygen. A man at rest consumes less oxygen and gives off less carbon dioxide than if he were at work. In a confined space, however, the air will finally become unfit to sustain life. Experiments have shown that a man in a confined space required approximately one cubic yard of air per hour. At the end of an hour this cubic yard of air will contain about fourteen per cent of oxygen and five per cent of carbon dioxide; an oil lamp will not burn, and an acetylene lamp will be almost extinguished. On the basis of one cubic yard of air per hour, an enclosed space which is ten feet wide, ten feet high, and ten feet long and contains one thousand cubic feet or thirty-seven cubic yards of space will support one man for thirty-seven hours before he begins to suffer through lack of breathable air. This minimum allowance of one cubic yard per hour per man, however, does not provide for loss of oxygen through absorption by the coal or timber in the enclosed space or for the impairment of the air by methane or carbon dioxide from the coal or rock. In some bituminous coal mines the oxygen behind seals is absorbed so rapidly that in one or two weeks there will not be sufficient oxygen left to support life.

In a metal mine a barricaded drift 250 feet long, 6 feet high, and 6 feet wide, containing 9,000 cubic feet of air, kept twenty-nine men alive for thirty-six hours. In the same mine another drift 130 feet long, 7 feet high, and 7 feet wide, containing 6,500 cubic feet, supported six out of eight men for fifty hours; the other two were found dead. The six who were alive were all unconscious but were later revived.

QUESTIONS FOR CHAPTER IX

1. What is the definition of a mine explosion? Gas explosion? Coal dust explosion?
2. Discuss the progress of flame through a gas-air mixture that is explosive.
3. In what way are gas and coal dust explosions similar?
4. How can blown-out shots, falls of roof, car wrecks, etc. contribute to coal dust explosions?
5. How do the pressure waves caused by a blown-out shot differ from the pressure waves resulting from an explosion of coal dust?
6. What is meant by the flame velocity of an explosion and what velocities have been recorded?
7. What temperatures are probably reached during coal dust explosions?
8. Discuss the shape of a coal dust explosion flame when the flame velocities are both low and high.
9. Discuss the formation of gases during a coal dust explosion.
10. Discuss the formation of coke during a coal dust explosion. Where is such coke usually found with respect to the direction of flame travel?
11. Can the origin of an explosion always be determined by the location of objects found in the mine after the explosion?

12. What is meant by "retonation" waves?
13. Discuss the influence of temperature and pressure on the explosibility of combustible mine gases.
14. What effect does moisture have on the explosibility of gases?
15. What is meant by "character of initial ignition impulse" and how does it affect explosibility of accumulations of explosive mine gases?
16. What effect does size of coal dust have on its explosibility?
17. Is the statement that "coal dust increases in explosibility with an increase in fineness" true?
18. What effect do the constituents have on the explosibility of coal dust?
19. What effect does the presence of explosive gas have on the explosibility of coal dust?
20. Is the statement that "anthracite coal dusts are not explosive" true? Discuss.
21. What is the minimum amount of coal dust necessary to propagate an explosion? What conditions affect this minimum quantity?
22. Is the statement that "the violence of an explosion increases as the amount of dust available increases" true? Discuss.
23. Where is the most explosive dust found along a haulage-

- way? Where is the least explosive dust found? What causes this to be true?
24. Discuss the sources of ignition that will start a coal dust explosion either with or without aid.
 25. At what points in the mine is coal dust made? What remedies would you suggest to eliminate or retard the production of dust at these points?
 26. What is meant by "effectively wetting coal dust"? Can this be done by humidifying the air current?
 27. How effective have chemical salt applications been in regard to moistening coal dust?
 28. What measures must be taken if coal dust is to be effectively wetted? In your opinion how much security would a mine in which the coal dust is dampened have against a coal dust explosion?
 29. Would a thorough "house-cleaning" of the mine passages absolutely prevent a coal dust explosion through complete removal of the dust? Explain.
 30. Compare rock dusting a mine with watering as to safety from explosions.
 31. Statements are frequently made that "the explosibility of a coal dust increases with its volatile matter content". Is this always true?
 32. Is as much rock dust required with coarse coal dust to prevent ignition or propagation as with the fine rib

or timber dust? Discuss.

33. Is as much rock dust required to prevent ignition as to prevent propagation?
34. What general methods can be applied to a mine to prevent or limit coal dust or gas explosions?
35. Describe the preparations and organization necessary on the outside of a mine to assist recovery operations where an explosion has occurred.
36. Describe the organization necessary to carry on the rescue and recovery work inside a mine where there has been an explosion.
37. Discuss the materials which a miner should collect if compelled to construct a barricade.
38. What are the most important points to consider in erecting barricades after an explosion?
39. Discuss the proper conduct of barricaded men to conserve the air supply.

CHAPTER X

MINE EXPLOSIVES

Lesson Subject:

Deflagrating and detonating explosives, safety fuse, electric detonators and delay detonators.

Lesson Objective:

The determination of the composition and properties of the different explosives, fuses, and detonators. The development of the best safety methods in storing and handling explosives.

CHAPTER X

MINE EXPLOSIVES

Types of explosives. Explosives are divided into two general classes, low explosives or those discharged by fire and high explosives or those that require a detonator. The explosives that are discharged by burning are called deflagrating explosives, and those that are discharged by shock are called detonating explosives.

In deflagrating explosives the force of the explosion depends upon the combustion of the powder and is a comparatively slow action due to the process of ignition of each particle through contact with another particle that is burning.

In detonating explosives the entire body of the explosive is ignited at one time by means of shock supplied by the detonating agent and the entire charge explodes at once resulting in a much faster action.

In both types the force comes from the expansion of the gases resulting from the combustion of the chemicals in the explosive with oxygen, and as explosives are always confined in use, it is necessary for all explosives to carry a source of oxygen in their own composition.

The chief low explosives used are gunpowder and black

blasting powder and the chief detonating explosives are nitroglycerin, dynamite and the permissible explosives.

Composition of black powder.³⁴ Black powder is the chief deflagrating explosive used in mines and is made of seventy-three parts of nitrate of soda (NaNO_3); sixteen parts of charcoal, and eleven parts of sulphur. Its force depends upon the rapid combination of the oxygen of the saltpeter with the carbon of the charcoal, the sulphur being added merely to make the mixture more easily lit. Its rate of explosion also depends upon the grain size--the powders being graded from CCC, which grains are about $36/64$ of an inch to FFFF, which grains are about $3/64$ of an inch in diameter. Pellet powder is grain powder pressed together in sticks weighing about one-half pound per stick. Black powder still remains the best agent for making lump coal. Its use has been largely discontinued, however, owing to the liability of fires from its use, dangers of igniting a dust explosion with its flame, and also the production of obnoxious gases chiefly, carbon monoxide and hydrogen sulphide, in its combustion.

High explosives. High explosives include nitroglycerin,

³⁴ Blasters Hand Book, Wilmington, Delaware, DePont De Nemours and Company

all of the dynamites, and the permissible explosives. These are all detonating explosives. That is, they are fired by shock from a detonator and the transfusion from solid to gas is much more rapid than that of a deflagrating explosive.

Composition of high explosives.³⁵ Nitroglycerin is prepared by mixing glycerin with sulphuric and nitric acids forming a dense oily liquid, which is very poisonous both in liquid form and through the inhalation of its fumes. It is very unstable and will explode if its temperature is raised to 360° F.

Straight dynamites are those that contain no other high explosive than nitroglycerin, wood pulp or flour, and sodium nitrate; the wood pulp acting as an absorbent for the nitroglycerin and the sodium nitrate furnishing the oxygen for the explosive.

Straight dynamites are classified from fifteen per cent to sixty per cent strength, the classification depending on the per cent of nitroglycerin present, as nitroglycerin will freeze at 52° F. The freezing points of these dynamites are considerably above 32°, usually about 42°. Great care should be used in handling frozen dynamite as freezing tends

³⁵ Blasters Hand Book, Welmington, Delaware, DePont De Nemours and Company.

to separate the nitroglycerin. In thawing some special device should be used and holes should never be tamped with frozen explosive. Storage houses should be kept as near 75° F. as possible at all times and dynamite when stored should be kept on its side and not on end, as storing on end will cause a concentration of the nitroglycerin in one end of the stick. To overcome this a slow or low freezing dynamite is made in which calcium carbonate and the other nitrous compounds are added to lower the freezing point.

The gelatin dynamites are used for wet blasting and are made by adding some nitro-cellulose to the nitroglycerin. This forms a jelly-like mass that is water proof and combined with a base of wood fiber or flour makes an explosive largely used in wet work. It is also a property of gelatin dynamite that if shot with a No. 8 cap it will give a harder explosive force than with a No. 6 cap.

Permissible explosives.³⁶ The United States Bureau of Mines defines a permissible powder as one that will pass the following tests. In determining these tests an amount of powder is used that is equal to one-half pound of forty per cent straight dynamite.

³⁶ "Recommendations of the United States Bureau of Mines on Certain Questions of Safety," Washington, D. C., 1936.

Test 1. Ten shots each with a charge described, in its original wrapper, shall be fired, each tamped with one pound of clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing eight per cent of gas (methane and ethane). An explosive is considered to have passed the test if no one of the ten shots ignites this mixture.

Test 2. Ten shots each with the charge described, in its original wrapper, shall be fired, each tamped with one pound of clay stemming, at a gallery temperature of 77° F., into forty pounds of bituminous coal dust, twenty pounds of which is to be distributed uniformly on a wooden bench placed in front of the cannon and twenty pounds placed on side shelves in sections 4, 5, and 6. An explosive is considered to have passed the test if no one of the ten shots ignites this mixture.

Test 3. Five shots each with one and one-half pound charge, in its original wrapper, shall be fired without stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing four per cent of gas (methane and ethane) and twenty pounds of bituminous coal dust, eighteen pounds of which is to be placed on shelves along the sides of the first twenty feet of the gallery and two pounds to be so placed that it will be stirred up by an air current in

such manner that all or part of it will be suspended in the first division of the gallery. An explosive is considered to have passed the test if no one of the five shots ignites this mixture.

Also to be permissible the powder undergoing the test must not liberate more than five and one-half cubic feet of poisonous gas to one and one-half pounds of powder. These permissible explosives are low grade dynamites whose ingredients have been selected to give a short relative cool flame and a reduced shattering effect. This is secured by a combination of nitroglycerin, ammonium nitrate, sodium nitrate, calcium carbonate, and a combustible base such as wood fiber. Water, being a product of the ignition of the combustion of these materials, cools and shortens the length of the flame.

In use these powders are no longer considered permissible when over one and one-half pounds is used in a charge; if the hole is not properly stemmed with incombustible material, or if the powder is used for solid shooting.

Permissible powders are supposed to have a safety factor of forty-five over black powder and seventeen over dynamite. In speeds the dynamite range from 6,500 feet per second, for twenty per cent permissibles to 18,000 for sixty straight dynamite.

Methods of firing explosives.³⁷ The common methods of firing explosives now in use are by means of fire, fuse, and detonators, electric detonators, and delay detonators. Squibs and electric squibs were formerly used, but today their use has largely been abandoned. Fuse, sometimes called safety fuse, consists essentially of a coil of fine grained powder wrapped about by threads of hemp, jute or cotton. These threads are wound in two sets, the innermost being called the spinning threads and the outer is the counter threads. In tape fuse the threads are wound with tape and then covered with powdered talc to prevent sticking. Fuses produce a large amount of CO when burning, and if an entire roll of fuse should catch on fire, its products would be extremely poisonous. Fuse will commonly burn two feet a minute, but the manufacturers make no guarantee to that effect.

Caps, or detonators as they are commonly called, consist of copper capsules charged with fulminate of mercury for about one-third of the length of the cap. Caps are commonly made in No. 6 and No. 8--size No. 8 being the stronger. Blasting caps are very sensitive to moisture and should always be kept in an air-tight box in a cool dry place. Electric blasting caps are designed to be fired by means of a dry cell

³⁷ "Safety in the Handling and Use of Explosives," New York, N. Y., Institute of Makers of Explosives, 1935.

or magneto. They consist essentially of a filament immersed in tetryl in the cap and covered with a coating of asphalt and sulphur. When an electric current is passed through the filament by means of the wire attached to each end, it becomes hot and ignites the fulminate of mercury. These caps come equipped with lead wires of copper or iron, ranging from four feet to twenty feet according to the needs of the purchaser. Under eleven feet, the wires are insulated with cotton; above eleven with enamel.

Delay detonators come in two types, delay caps and delay igniters. Delay blasting caps are manufactured in ten different delay times and are so constructed that there is a short lapse of time after the current is applied before the first delay explodes, with a longer interval before the second delay explodes and so on before each delay explodes.

In delay electric igniters there is a short length of fuse below the electric wiring to which an ordinary detonating cap must be attached before using. In use electric igniters should not be intermixed with electric delays; also products of different companies should not be intermixed as their delay speeds are not the same for the same number of delays.

In connecting shots two types of wiring may be used, series or series parallel. Series parallel is recommended where over four or five shots are to be fired.

In making and charging all types of explosives the directions provided by the manufacturer on each box of explosives should be carefully followed and powder and caps should be transported and stored underground in accordance with the following statutes of the state law. 38

"Every owner or operator who is engaged in any such industry where powder is stored in carload lots for future use, shall maintain a suitable powder-house not less than 500 feet from the mouth of the workings: Provided, that not more than 200 pounds of powder may be stored not less than 250 feet from the mouth of the workings for immediate use when blasting is being done.

It shall be unlawful to have any keg of powder or part thereof, or other explosive in the mine except in a tight wooden box, the type and kind to be approved by the department of inspection of mines and mining, secured by a suitable lock, and such box shall not be placed at a less distance than seventy-five (75) feet from the working face; or to have any detonator or dynamite caps within five feet of any powder, at any one time. Said detonators or dynamite caps shall be placed in a secure container, and shall not be placed nearer than five feet from any powder, dynamite or other explosive.

Whenever any person is about to open a keg or box containing powder, or other explosives, he shall place and keep his light at least five feet distant from said explosive, and in such position that the air current cannot carry sparks to it; and no person shall approach nearer than five feet to any open box or keg containing powder or other explosive with a light or pipe or any thing containing fire."

38 Mining Laws of Indiana, Indianapolis, Indiana, Section 6, paragraph 87.

Detonating caps should always be placed at the outer end of the charge for maximum explosive power. Wooden tamping sticks should be used and all holes tamped with incombustible material. If a shot misses when fuse is used, it should not be returned to under twenty-four hours; if electric blasting is used, fifteen minutes is considered a safe time to go back on the charge. This time, however, does not apply to delay caps, which should be given ample time before returning to the shot. Where shots are missed another hole should be drilled not closer than two feet from the missed hole and the missed shot blasted out and the charge recovered.

QUESTIONS FOR CHAPTER X

1. What is black blasting powder?
2. How is black powder fired?
3. What are the dangerous gases formed by black powder?
4. What precautions should be taken in preparing black powder in an open light mine?
5. What are the dangers of using black powder?
6. What is pellet powder?
7. What is a dynamite?
8. What are the three principal classes of dynamite?
9. Is straight dynamite permissible?
10. What gases are given off in a dynamite explosion?
11. What are the principal objections to the use of dynamite in a coal mine?
12. What are the dangerous gases produced in shooting dynamite?
13. What are permissible explosives?
14. What tests do they have to pass to be designated as permissible?
15. What is the maximum volume of poisonous gases allowable for one and one-half pounds charge of permissible explosives?
16. Besides the characteristics of their ingredients, what other conditions determine the permissibility of an

- explosive?
17. What is the maximum amount of permissible powder allowed in any one hole?
 18. Are permissibles more sensitive to moisture than other dynamites?
 19. Why is the use of coal dust for tamping not desirable?
 20. What kind of a tamping tool should be used?
 21. What may be the danger of an undercharged hole?
 22. What is meant by cushion shooting?
 23. What is the danger of mud capping?
 24. What creates the fire when any explosion is fired?
 25. How many premature shots be caused when electric detonators are used?
 26. How may premature shots be caused where fuse is used?
 27. How long should a person remain away from the face when a misfire occurs with a shot fired with fuse?
 28. What are the laws of the state of Indiana regarding the storage of powder?
 29. What are the laws of Indiana regulating shot firing?
 30. How should explosives be transported in a mine?
 31. What precautions should be used in firing shots electrically?
 32. Where should the detonator be placed when a hole is charged?

CHAPTER XI

STATE LAWS

Lesson Subject:

The study of the state laws of Indiana as they apply to the production of bituminous coal.

Topics to be Studied:

Laws covering safety and sanitation in Indiana mines.

Lesson Objective:

To become familiar with laws on the statute books of Indiana that are designated to insure safe working conditions for Indiana miners.

CHAPTER XI

STATE MINING LAWS

The following questions and answers are designed to bring out the main features of the mining laws, but their study should be accompanied by a study of the entire text of the laws. In the application of the laws the mine superintendent is usually considered the acting agent of the owner or operator.³⁹

Q. What are the duties of the mine operator in regard to making mine maps?

A. "The operator of each mine shall make or cause to be made an accurate map or plan of the workings of such mines on a scale of not less than two hundred feet to one inch, showing the area mined or excavated, the arrangement of haulage roads, air courses, breakthroughs, brattice, air bridges, or overcasts, and doors used in directing the air currents in such mine, the location and connection with such excavation of the mine of the lines of all adjoining lands with the names of the owners of such lands so far as known, marked on the map. Such map shall show a complete working of the mine, and, when completed, shall be certified to by the operator, agent, or engineer making the survey or map to be a true and correct working map of said mine."

B. "The operator or agent shall deposit with the chief inspector of mines a true copy of such map within thirty days after the completion of the survey of the same, the date of which shall be shown on each copy, the original map and survey

³⁹ Mining Laws of Indiana, Indianapolis, Indiana, Bureau of Mines and Mining, 1941.

to be kept at the office of such mine open for inspection of all interested persons at all reasonable times. Such map and copy thereof, shall be extended each year between the first day of May and the first day of September, and shall be filed as required in making the original survey showing the exact workings of the mine at the date of the last survey." (Page 5, paragraph 7, Sec. 2. State Mining Laws)

Q. What pillars must be left by the mine operator at the mine boundaries?

A. "It shall be obligatory upon the operators of adjoining coal properties to leave, or cause to be left a pillar of coal, fifteen feet in width on each side of the property line in each seam or vein of coal worked by them." (Page 8, paragraph G)

Q. What is the duty of the mine operator when any part of the mine is abandoned?

A. "Before a mine or any part of a mine is abandoned, the owner or agent shall make a survey showing the farthest extremity of the workings of such mines, and a map thereof made and filed within thirty days thereafter at the office of the county recorder in the county where such mine is located; said map shall have attached thereto the affidavit of the mining engineer making the map, and of the mine boss in charge of the underground workings of said mine. Such map shall be properly labeled and filed by the recorder and preserved as a part of the records of the land on which said mine is located, and the recorder shall receive for said filing from said owner or agent a fee of fifty cents." (Page 10, paragraph 10, Sec. 10)

Q. What are the precautions that must be used by the mine operator in approaching abandoned workings and in working two or more veins by the same mine?

A. "The entrance of an abandoned mine shall be securely fenced off by the owner of said land on which said entrance is located, so that no injury can arise therefrom."

"When approaching abandoned workings which are supposed to contain dangerous accumulation of water or gases, the excavation approaching such places shall not exceed eight feet in width, and there shall be constantly kept, at a sufficient distance (not less than three yards in advance) one bore hole near the center of the workings and sufficient flank bore holes on each side." (Page 11, paragraph B & C of Sec. 4)

Q. What restrictions are placed on working men in mines that have only one shaft?

A. "It shall be unlawful for any operator to allow more than ten (10) persons to work in any mine at any one time after five thousand (5,000) square yards have been excavated, until a second outlet shall have been made." (Page 11, Sec. 5)

Q. What are the provisions of the state laws in regard to escape shafts?

A. "Provided, That all air and escape shafts sunk hereafter shall be separated from the hoisting shaft by at least two hundred (200) feet of natural strata, and shall be provided with stairways not less than two (2) feet in width, at an angle of not more than fifty (50) degrees, with landings at easy and convenient distance, and with guard rails attached to each set of stairs from the top to the bottom of the same, and shall be available at all times to all employees engaged in such mines; also, Provided, That the stairways, landings and guard rails shall be of suitable design and strength to accomplish the purpose for which they are intended, and shall be kept free from obstructions. And that when the escape and air shafts are combined, the escape and air shafts shall be separated by a good, substantial partition from top to bottom: Provided, further, Where the approach or approaches to the

escape shaft crosses an air course, entry or other passageway used as an air course, either as an intake or return, the air current shall be conducted by an overcast or undercast, over or under the point where such approaches cross the air course, and that all approaches to escape shafts shall be kept free from falling slate, mine tracks, mine cars and other debris, and shall be used only as a means of ingress or egress to or from the escape shaft."

B. "All water coming from the surface or out of any strata in such shaft shall be conducted by rings or otherwise to prevent it from falling down the shaft and wetting persons who are descending or ascending the shaft."

C "In lieu of the stairway hereinabove provided for, the operator may provide at such outlet or escape shaft a hoisting apparatus, which shall be at all times available to all persons in the mine, the same signals to be used as provided by law for use at hoisting shafts."

D. "The traveling roads or gangways to said outlet shall be separated from the hoisting shaft by at least two hundred (200) feet of natural strata, and not less than four (4) feet in height and four (4) feet wide, and shall be kept free from water as the average haulage roads in such mines."

E. "At all points where the passageway to the escapement shaft or other place of exit, is intersected by other roadways or entries, conspicuous boards shall be placed indicating the direction it is necessary to take in order to reach such place of exit."

F. "It shall be unlawful to erect any inflammable structure or building or powder magazine on the surface so near the escapeway as to jeopardize the safety of the workmen in case of fire."

G. "Fans shall be located and maintained at such place as not to be directly over the opening of an air shaft or escapement shaft, and all fans hereafter installed shall be arranged as to enable the operator, when desirable, to reverse the air

current: Provided, further, That escape shafts already constructed under the provisions of the law prior to the year 1913 shall not be affected by this act, except, they shall be maintained according to the provisions herein."

H. "All escape shafts and underground approaches thereto shall be examined at least once each week or oftener if necessary, to keep same in safe condition. A telephone shall be installed at the top and bottom of each mine and at the main partings therein. That hereafter when any oil or gas well is drilled through any coal seam in this state and shall have been abandoned, any person, firm or corporation drilling the same, shall properly plug such drill hole above and below each coal seam and file a map showing the exact location of such drill holes with the recorder of the county where such land is located." (As amended by Acts 1925, page 412) (Page 11, 12, 13, 14)

Q. What are the requirements of the state laws in regard to hoisting apparatus, cages, and safety devices on cages?

A. "The rope used for hoisting and lowering in every mine shall be a wire rope, and it shall be securely fastened to the shaft of the drum where two separate ropes are used, and at least one whole lap shall remain on the drum when the cage is at rest on the lowest caging place in the mine, and it shall be examined by some competent person every morning before the men descend into the mine."

B. "The operator of every mine shall provide a cover one-fourth inch boiler plate overhead on all carriages or cages used for lowering or hoisting persons into and out of the mines, and on top of every shaft an approved safety gate; also an approved safety spring on top of every slope. Approved safety catches shall be attached to every cage used for the purpose of hoisting or lowering persons."

13. "Brake: An adequate brake shall be attached to every drum used for lowering or raising persons into or out of all shafts or slopes."

14. "Indicator. F. An approved indicator shall be attached to every hoisting apparatus in addition to any mark on the rope, which shall show to the hoisting engineer the position of a cage or load in the shaft or slope."

G. "The operator of every mine shall keep the top and the entrance thereof securely fenced off by vertical or flat gates, covering and protecting the mouth of such mine. Two lamps shall be kept lighted at all times when the mine is in operation, except when electric lights are used, one on each side of the shaft, not more than ten (10) feet from said shaft in each vein where men get on or off the cage. There shall be gates hung at each vein, other than the lower one, so that at all times, except when coal is actually being taken off the cage, there shall be a barrier preventing anyone falling into the shaft." (Page 15, Section 6, paragraph A & B and paragraph 13 & 14 on page 16 and 17)

Q. What are the provisions of the state laws in regard to persons riding cages?

A. "All persons are prohibited from riding on the cages when coal or dirt is being hoisted."

D. "It shall be unlawful for any person desiring carriage upon any cage to approach nearer than six (6) feet to any "cage" landing when such cage is not at rest at such landing; or to crowd onto said cage in a rude or boisterous manner; or to enter upon any such cage when there are already upon the same, one person for each three square feet of the floor space of such cage: Provided, That nothing herein contained shall affect any person in charge of the operation of such cage, or the machinery moving or affecting the same: and, Provided, further, That, as many persons may, after the passage of this act, enter a cage for carriage as the same will accommodate, giving each person three square feet of floor space." (Paragraph C & D on page 15 & 16)

Q. What is the code of signals in use in Indiana mines?

A. E. "There shall be a code of signals at all mines, with a signal bell at the top and bottom of each mine. One bell shall signify to hoist coal, or empty cage, and also to stop either when in motion; two bells shall signify that men are coming up; when return signal is received from the engineer, men will get on the cage and ring one bell to hoist; four bells shall signify to hoist slowly, implying danger. The engineer's signal for men to get on the cage shall be three bells. A whistle may be used at the top of the mine instead of a bell. A copy of the above code shall be printed and conspicuously posted at the top and bottom of the shaft and in the engine room." (Paragraph B, page 18)

Q. What is the law as to how the hoisting engine and cage must be managed?

A. H. "The operator shall not place in charge of any engine used for conveying into or hoisting out of any mine any but certified and sober engineers."

I. "The engineer in charge of such engine shall allow no person, except such as may be deputed for that purpose by the operator or agent, to interfere with it or any part of the machinery, and no person shall interfere, or in any way intimidate the engineer in the discharge of his duties. He shall not permit anyone to loiter in the engine room, and he shall hold no conversation with any officer of the company or other person while the engine is in motion, or while his attention should be occupied with the business of hoisting. A notice to this effect shall be posted on the engine house in some conspicuous place. He shall thoroughly inform himself of the established code of signals. Signals must be delivered in the engine room in a clear and unmistakable manner, and when the signal is received that men are on the cage, said cage shall not travel to exceed six hundred (600) feet per minute." (Paragraph H & I, page 17 & 18)

Q. How much air must be furnished by the operator?

A. Sec. 10. A. "The operator of every mine shall provide and maintain, hereafter, for every such mine, a sufficient amount of ventilation affording not less than one hundred (100) cubic feet of air per minute for each and every person employed therein, and three hundred (300) cubic feet per minute for each mule, horse, or other animal, in said mine, measured at the intake of the split or subdivision of the air, and as much more as the circumstances require." (Page 21)

Q. What are the provisions of the law as to the use of booster fans?

A. C. "The ventilation required by this act, may be provided by any suitable appliance or appliances, but in no case shall a booster fan be installed in the inside workings of a mine engendering dangerous explosive gases, without having secured a permit from the chief inspector of mines in writing, to install such booster fan: Provided, That this provision relating to booster fans, shall not be applicable to mines using booster fans prior to the year 1921." (Page 22, paragraph C)

Q. What are the qualifications necessary to secure a certificate as mine boss or fire boss?

A. "Certificates of competency shall be issued by the chief inspector of mines to any person who is at least twenty-one years of age and who shall prove satisfactory upon such written examination, as may be prescribed by such chief inspector, that he is qualified by experience and technical knowledge to perform the duties of either mine boss, fire boss or hoisting engineer."

"Every mine boss must be a certified fire boss, and every room boss must be a certified fire boss and mine boss in the mines that generate explosive gas." (Paragraph K, page 66 & paragraph N, page 67)

Q. What are the duties of the mine boss?

A. "The operator shall employ a certified, competent mine boss who shall be an experienced coal miner,

and shall keep careful watch over the ventilating equipment, and the airway, and shall see that as the miners advance their excavation, all loose coal, slate, and rock overhead, are taken down, or carefully secured against falling on the traveling airways."

"The mine boss shall measure the air currents at least once a week at the inlet and outlet, and at or near, the face of the entries; he shall keep a record of such measurements, which shall be entered in a book kept for that purpose; the said book shall be open for inspection of the chief inspector of mines. The mine boss shall also, on or about the first day of each month, mail to the chief inspector of mines a true copy of such air measurements, stating also the number of persons employed in or about said mine, the number of mules or horses used, and the number of days worked in each month."

"The mine boss shall visit and examine every working place in the mine at least every alternate day while the miners of such place are, or should be, at work, and shall examine and see that each and every working place is properly secured by timbering, and that the safety of the mine is assured. He shall see that a sufficient supply of timbers are always on hand at the miner's working place. He shall also see that all loose coal, slate and rock overhead, wherein miners have to travel to and from their work, are taken down, or carefully secured."

"Whenever, such mine boss shall have an unsafe place reported to him, he shall order and direct that the same be placed in a safe condition; and until such is done, no person shall enter such unsafe place, except for the purpose of making it safe. Whenever any person working in said mine shall learn of such unsafe place he shall at once notify the mine boss thereof, and it shall be the duty of said mine boss to give him, properly filled out, an acknowledgement of such notice of the following form: I hereby acknowledge receipt of such notice..... of the unsafe condition of the mines as follows.....
Dated thisday of19..

.....
 Mine Boss."

"The possession by the person of such written acknowledgement shall be proof of the receipt of such notice by said mine boss whenever such question shall arise; and upon receipt of such notice, said mine boss shall at once inspect such place and proceed to put the same in good and safe condition. As soon as such unsafe place has been repaired to the approval of said mine boss, he shall then give permission for the men to return to work therein, but no person shall return to work therein until such repairs have been made and permission given."

"Whenever any accident whatsoever has occurred in any mine which shall delay the ordinary and usual workings of such mine for twenty-four consecutive hours, or has resulted in such injury to any person as to cause death, or require the attendance of a physician or surgeon, it shall be the duty of the person in charge of such mine, to notify the chief inspector of mines of such accident, without delay." (Paragraph E & F, page 23 and paragraph A, B & C, page 39-40)

Q. What are the duties of the fire boss?

A. "Every mine where firedamp is known to exist, shall be carefully examined with a safety lamp by a certified, competent fire boss, immediately before each shift, and in making said examination, it shall be the duty of the fire boss at each examination, to leave at the face of every place examined, evidence of his presence; and it shall be unlawful for any person to enter any mine or part of the mine generating firedamp, until it has been entered and examined by the fire boss and reported by him to be safe. The fire boss shall, further, report any injury or defects in the brattice, trap doors, regulating doors, and overcasts, where such injury or defect may cause a derangement or diminution of the ventilating air current. The fire boss shall make note of, and report any dangerous or unlawful conditions in the working places of the mine, and report the same in a suitable manner to the mine boss, whose duty it shall be to see that such dangerous or unlawful conditions are corrected and made safe before men shall enter therein." (Paragraph B, page 21)

Q. What are the provisions of the continuous inspection law?

A. "That in all coal mines in this state where noxious or dangerous gases are known to be generated or exist therein, or coal dust exists in dangerous quantities, the owner, operator or lessee of such mine shall employ at least one licensed fire boss, and as many more as needed and required, to make hourly and continuous inspections, and tests for noxious or dangerous gases or other poisons, at the place(s) where dangerous or noxious gases exist(s) in said mine, each day such mine is in operation; Provided, That employees and day men who are qualified fire bosses and are employed underground may be directed to make the inspections required under this act. Such inspections shall be made in addition to the inspections now required by law, of the condition of the air and dust in such mine and in the working places of all the men employed in such mine, together with the inspection of the various entries and other places therein. In case such fire boss shall find any dangerous gases or coal dust to exist in such mine or any other dangerous poison or condition to exist, he shall immediately order all of the men out of said mine, or section of the mine where such dangerous condition exists, until such noxious or dangerous gases or coal dust shall have been removed, remedied or expelled from said mine."

"For the purpose of assisting in the making of such inspections and tests, when the operation in any mine approaches any abandoned workings of the mine, or any abandoned mine, where, or in which, there may be dangerous accumulations of water or gas, and when such operations have approached within fifty(50) feet of abandoned workings in the same, or some other mine, the owner, operator or lessee of such operated mine shall cause to be kept one drill hole not less than fifteen (15) feet in advance of the operation near the center of the workings and sufficient flank drill holes on each side of each operated place farthest advanced to the abandoned works or abandoned mine, to give advanced knowledge of the presence of dangerous accumulations of water or gas in such abandoned workings or abandoned mine or mines."

"Where there are falls of the roof near the places of abandoned workings or in the vicinity of abandoned mines or where what is known as a "squeeze" exists in any section of the mine, the inspections shall be continuous and at such frequent intervals, that such inspectors may obtain advance knowledge of the presence, existence or approach of dangerous gases or other dangerous conditions, in ample time to furnish warnings to all men working in the mine. When any conditions are found to exist, he shall immediately cause all men in such dangerous section or sections to be withdrawn from the mine until such dangerous conditions are removed or remedied." (Section 82, page 82)

Q. What are the provisions of the law as to distance that breakthroughs shall be made?

A. "Breakthroughs or airways shall be made in each room and entry at least every forty-five (45) feet. All "breakthroughs" or airways, between entries, except those last made near the working face of the entry, shall be closed up and made air tight." (Page 24, paragraph I)

Q. What are the provisions of the Indiana law regarding the use of trolley wire and trolley motors?

A. "In all coal mines of the State of Indiana, all trolley wires crossing places on main haulage roads where persons or animals are required to travel, shall be safely guarded and protected by substantial, efficient board, or other guards, so that such person or animals passing thereunder shall not come in contact with said trolley or other live wire."

"All trolley wires, when placed along travelways or haulage roads, shall be placed on one side of said haulage road and trolley wire shall not be placed less than five (5) inches outside of the rail or track."

"All underground trolley wires shall be securely supported upon efficient and approved insulated hangers, and all trolley wires kept taut at all times."

"There shall be an efficient headlight on all motors in mines, when in use."

"On every motor trip of cars on the main haulage roads, there shall be an efficient bell, red light, or other device approved by the department of inspection of mines and mining upon the rear end of said trip, and the motorman in charge of said motor is hereby prohibited from making said trips unless one of said devices is properly placed thereon."
(Page 27, paragraph A, B, C, D & E)

Q. What are the laws in regard to the use and installation of electricity underground?

A. "Hereafter where electricity is installed no higher than two hundred seventy-five (275) volts shall be used underground, except for transmission, or for application to transformers or other apparatus, where the high voltage circuit is stationary. High voltage motor, and transformers, shall be installed in suitable chambers built of fire proof construction, and well ventilated, and shall not be placed on intake, or between intake and return air courses. All high voltage lines and apparatus must be clearly marked, to indicate their danger. Main and distribution switchboards for high voltage, shall be made of insulating and incombustible material, such as marble or slate, and to be free of all metallic veins, or of material equivalent thereto. Same shall be installed in a dry place. All switches or other instruments used in connection with high voltage shall be installed on suitable switchboards, with at least three (3) foot passageway in front and rear properly floored, and kept locked by a door at each end that can be opened from the inside without a key. With higher than medium voltage, there shall not be any live metal work on the front of switchboard, and the entry circuit must be protected by an oil breaker switch on each pole equipped with automatic overlap trip."

"To insure safety, all conductors with higher than medium voltage, shall be provided with sufficient insulation of standard manufacture and steel armored covering, or its equivalent, covering to be grounded at least every four hundred (400) feet. No grounding of phase of alternating current shall be

permitted. All branch trolley lines shall be provided with automatic trolley switches, or sectional insulators, or line switches, or other devices to cut off the current. All joints and conductors shall be mechanically and electrically efficient. When joints are completed, they shall be insulated to the same extent as the rest of the wire. Both rails on main haulage roads shall be bonded and cross-bonded at points not to exceed three hundred (300) feet apart. All apparatus, such as transformer cases or switch cases, generators or motor frames and pipe work on rear of switchboards, shall be properly grounded."

"By low voltage herein is meant a voltage of less than one hundred ten (110) volts. By medium voltage herein is meant, a voltage ranging from one hundred ten (110) volts to two hundred seventy-five (275) volts. By high voltage herein is meant, a voltage above two hundred seventy-five (275) volts."

Q. What are the state laws in regard to the use and care of explosives?

A. "It shall be unlawful to have any keg of powder or part thereof, or other explosive in the mine except in a tight wooden box, the type and kind to be approved by the department of inspection of mines and mining, secured by a suitable lock, and such box shall not be placed at a less distance than seventy-five (75) feet from the working face; or to have any detonator or dynamite caps within five (5) feet of any powder, dynamite or other explosives, or to have more than ten detonators, or dynamite caps at any one time. Said detonators or dynamite caps shall be placed in a secure container, and shall not be placed near than five (5) feet from any powder, dynamite or other explosive."

"Whenever any person is about to open a keg or box containing powder, or other explosives, he shall place and keep his light at least five (5) feet distant from said explosive, and in such position that the air current cannot carry sparks to it; and no person shall approach nearer than

five (5) feet to any open box or keg containing powder or other explosives with a light or pipe or anything containing fire." (Page 30 & 31, paragraph A & B)

Q. What material must be used for tamping?

A. "It shall be the duty of the operator or owner of any coal mine wherein fire clay or other non-inflammable material suitable for use in tamping in preparing shots cannot be readily obtained, to provide and deposit within said mine, such material, and at points within five hundred (500) feet from the face of each entry in such mine. In case any dispute may arise as to the duty of any such operator or owner thereunder, such dispute shall be finally determined by the chief inspector of mines." (Page 33, paragraph G)

Q. What are the provisions of the law in regard to tamping?

A. "In the process of charging or tamping a hole, no person shall use any iron or steel needle or tool, except as herein provided. The needle used in preparing the blast shall be made of copper, and the tamping bar shall be tipped with at least five (5) inches of copper. No coal dust or any material that is inflammable, or that may create a spark, shall be used for tamping, and some soft material shall be placed next to the cartridge, or explosive." (Page 34, paragraph H)

Q. What is the law governing shooting while men are in the mine?

A. "The superintendent or mine manager shall not permit the shot firer or firers to do any blasting, exploding of shots, or do any firing whatever, until each and every miner and employee is out of the mine except the shot firer or firers, mine superintendent, mine manager and men necessarily engaged in charge of the pumps and stables: Provided, however, That nothing in this section shall be construed to prohibit the employment in such mine of a reasonable necessary number of men,

during such time, for the purpose of securing the workings in case of fire therein." (Page 36, paragraph D)

Q. What are the requirements of the state law covering traveling ways?

A. There shall be cut at the bottom of the shaft, a traveling way, sufficiently high and wide to enable persons to pass the same in going from one side to the other, without passing over or under the cage."

"On all single track hauling roads, wherever hauling is done by power, and on all gravity or incline planes in mines, upon which the persons employed in the mines must travel on foot to and from their work, places of refuge must be provided in the side wall, not less than three (3) feet in depth, measuring from side of car, and four (4) feet wide and not more than twenty (20) yards apart, unless there is a clear space at least three (3) feet between the side of the car and the side of the wall, which space shall be deemed sufficient for the safe passing of men."

"On all hauling roads in which the hauling is done by draft animals, whereon men have to pass to and from their work on foot, places of refuge must be cut in the side wall at least two and one-half ($2\frac{1}{2}$) feet deep, measuring from the side of the car, and not more than twenty (20) yards apart, but such places shall not be required in entries from which rooms are driven at regular intervals not exceeding twenty (20) yards, and whenever there is a clear space of two and one-half ($2\frac{1}{2}$) feet between the car and the rib, such places shall be deemed sufficient for the safe passage of men."

"All places of refuge shall be whitewashed and kept clear of obstructions, and no material shall be stored therein, excepting in cases of emergency, nor be allowed to accumulate therein." (Page 40, Sec. A, B, C & D)

Q. What first aid supplies must be furnished by the operator?

A. "At every mine where ten or more men are employed inside, it shall be the duty of the operator thereof, to keep always on hand, readily accessible and near the mouth of the mine, a properly constructed and comfortable stretcher, a woolen and waterproof blanket, a roll of bandages in good condition for immediate use for bandaging wounds of anyone injured in such mine; a supply of linseed oil, lime, camphor, turpentine, antiseptic gauze, dressing and surgeon's splints for the dressing of broken bones; also to provide comfortable apartment near the mouth of the mine, in which anyone so injured may rest while awaiting transportation to his home, and to provide for the speedy transportation of anyone injured in such mine to his home." (Page 44, paragraph J)

Q. What is the law in regard to the use of life checks?

A. "Every person, firm, corporation, partnership or association operating a coal mine in the State of Indiana shall at all times provide a book, check, token or other method of registration for all persons entering or leaving such mine." (Part of paragraph L, page 45 & 46)

Q. What are the qualifications of a state mine inspector?

A. "A governor shall appoint a chief mine inspector for a term of four years. The chief mine inspector, with the approval of the governor, shall appoint five assistant mine inspectors for a term of four years. No person shall be appointed chief mine inspector, or assistant mine inspector, who has not had ten years' experience as a practical miner. The governor may remove the chief mine inspector, and the chief mine inspector may remove any assistant mine inspector at any time, for cause. The chief mine inspector, with the approval of the governor, may employ and fix the salary and compensation of such clerks, stenographers and assistants, as may be necessary to carry on the work of the board." (Page 2, Sec. 3)

Q. What mines in Indiana must be rock dusted?

A. "Rock dust shall be distributed on all main haulages, on all entries, to the last breakthroughs, on said entries, and to the first breakthrough in all rooms and pillar workings, protected rock dust barriers shall be erected, and in all open works to within forty five (45) feet of the working face, and such protection shall be afforded by rock dust barriers, as may be found necessary by the state mine inspector. Rock dust shall be distributed upon top, bottom, and sides of all return airways where hauling or traveling is done." (Page 76, paragraph 92)

Q. How shall isolated panels be protected?

A. "In isolated panels in which no exposed electric circuits, or non-permissible motors are used, and in which permissible safety lamps and explosives are used, protection shall be given by rock dusting the entries and by rock dust barriers at each entrance and exit." (Page 76, paragraph 93)

Q. How may sections in which there is no track or traveling be protected?

A. "In other places in which no traveling or hauling is done, the rock dust may be distributed by the air current into which it is blown: Provided, That the amount specified in this act is distributed, or such places may be protected by rock dust barriers which shall be subject to the approval of the state mine inspector. Such barriers shall be erected where they will stop an explosion either before leaving or entering each panel or section of a mine." (Page 77, paragraph 94)

Q. What kind of rock dust must be used?

A. "The kind of rock dust used shall not contain more than five per cent of combustible matter, not more than twenty-five per cent of quartz or free silica particles, nor absorb moisture from the air to such an extent as to cake and destroy its effectiveness as a dry dust. It may be made from limestone, shale or other inert material which meets the foregoing specifications. The lighter colored dust shall be preferred. The dust

to be used shall be pulverized, so that one hundred per cent will pass through a sieve having twenty meshes per linear inch, and fifty per cent more will pass through a sieve having two hundred meshes per linear inch." (Page 77, paragraph 95)

Q. How much rock dust must be used?

A. "In all places where rock dust is distributed, enough shall be used so that the percentage of incombustible material in the samples of dust collected shall be maintained at least at fifty-five per cent. Along room entries or gangways where methane gas is found in the ventilating current, the amount of incombustible materials above specified shall be raised ten per cent for each one per cent of gas. Where rock dust barriers are installed, the amount of dust used shall be at least one hundred pounds per square foot of average cross section of entry, at the barrier zone." (Page 77, paragraph 96)

Q. What are the provisions as to sampling and keeping a record of rock dusting?

A. "Samples of dust shall be gathered every month from the road, roof, rib and timbers on each split of air, and tested to determine if any part of the mine requires redusting. The method of analyzing or testing recommended by the United States Bureau of Mines, and approved by the state department of mines and mining, shall be employed. The dust in all barriers shall be inspected monthly and shall be kept in such condition that when the barriers come into play the dust will fall loosely into the air."

"A written record shall be entered in a book kept for that purpose in the mine office, showing the location at which samples have been taken, and the results of the analysis. A map of the mine shall be kept available for inspection." (Page 78 & 79, paragraph 97 & 98)

TABLE VI
 TABULATION BY PERCENTAGES OF AFFIRMATIVE
 ANSWERS FROM TWO HUNDRED FIVE QUESTION-
 NAIRES RETURNED BY MINERS AND SIXTY-THREE
 BY MINE FOREMEN

Question	Miners	Foremen	Question	Miners	Foremen	Question	Miners	Foremen
1	100	100	22	96	100	43	99	100
2	100	100	23	100	100	44	99	100
3	88	92	24	84	81	45	97	100
4	3	15	25	53	61	46	43	53
5	17	34	26	17	43	47	38	72
6	87	92	27	100	100	48	84	89
7	98	100	28	23	83	49	98	100
8	13	41	29	49	58	50	72	78
9	77	82	30	88	97	51	72	78
10	21	55	31	43	67	52	94	87
11	21	55	32	88	85	53	100	100
12	12	96	33	75	83	54	100	100
13	92	91	34	67	87	55	82	91
14	84	100	35	24	82	56	57	68
15	100	100	36	19	34	57	68	68
16	78	68	37	19	33	58	21	57
17	93	100	38	12	21	59	98	99
18	99	98	39	28	42	60	79	81
19	63	88	40	5	14	61	69	70
20	88	88	41	87	94			
21	82	91	42	93	100			

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