TWENTY LESSONS IN

Locomotive Fuel Economy

:: :: EXAMINATION :: ::
QUESTIONS AND ANSWERS

THREE EXAMINATIONS

. . . BY FREDERICK J. PRIOR . . .

BEING ONE OF THE SERIES OF THE PRIOR SYSTEM OF SELF-EDUCATIONAL TEXT AND REFERENCE BOOKS

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TO

John N. Conshafter

once a railroad man, now a successful man
of affairs, who has attained marked
distinction, this book is affec-
tionately dedicated by its
author.

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FOREWORD.

"Instruction is only half the battle," says Emerson.

It is safe to say there is no other class of labor that more fully realizes the truth of this than locomotive enginemen.

Locomotive Firemen must have technical instruction, must study, must have practical experience, and must pass graded examinations before qualifying as locomotive engineers.

Locomotive Engineers must continually search after knowledge. The instruction previously received being intended to bring out their latent strength. The experience, labor, observation and practice they get in the school of hard work all combine to develop and perfect what is so absolutely essential—GOOD JUDGMENT.

To earnest men seeking to develop the "MASTER MIND" and to be masters of their work, study of seemingly dry subjects becomes interesting; especially when, as in this book, a sincere effort has been made to invest even dry topics with an interest that fascinates and instructs.

INTRODUCTION.

These questions cover the Three Examinations embodied in the Twenty Lessons on Locomotive Fuel Economy as required by some railroads.

It would be foolish to think for a moment that these answers may be copied or learned for the purpose of passing the required examinations.

The book of "Instructions for Locomotive Fuel Economy" furnished to engineers and firemen by the railway company must be **thoroughly studied** in order to have a proper understanding of these definite answers, every one of which is based upon the instructions contained in the book mentioned.

Moreover, when reading the questions and their answers the Instruction Book should be at hand to be studied in connection with them. Notice that at the beginning of each question there are enclosed in brackets, the letter T and a number. The letter T refers to the topic (or subject) of the question and its answer, and the number refers to the number given to the topic at the beginning of each topic in the Instruction Book. These topics should be read over many times if necessary, in connection with each question and its answer. Only by doing this and combining EXPERIENCE and OBSERVATION with this study can a clear and thorough understanding be had of the purpose and meaning of each question and its answer.

CUSTOMARY RULES

Governing Manner of Writing Examinations as Required by Some Railway Companies.

The three Examinations may be written at one time, or at different times, as the Student prefers. More than one sitting for each Examination will be allowed if necessary; but the Student should prepare, by careful study, to go through at least one complete Examination at each sitting.

The Examinations are to be written by the Student before an Officer of the Company or his Representative. Consulting the **Instructions**, while doing this, will only be permitted to answer the ★ questions.

Give clear, correct and short Answers. The number in parentheses with each question indicates the **Topic** that treats the **Subject**.

FIRST EXAMINATION

ECONOMICAL FIRING

LESSON I.—IMPORTANCE OF FUEL ECONOMY.

1. (T-1) What is the first necessity of every working locomotive?

Sufficient steam for the work it must do. It is a vital necessity. The motive power is absolutely dependent upon steam.

2. (T-2) What is the Company's annual expense for locomotive fuel?

(State the sum if known.)

3. (T-2) Why is economy in the use of fuel necessary?

Because fuel is property and should not be wasted or destroyed. Next to wages fuel is the largest outlay the Company has. It is as necessary to be careful of fuel and to practice economy in its use as it is to avoid smashing cars or doing damage to other property of the Company.

4. (T-2) Do you appreciate the necessity of economizing in the use of this most expensive supply as much as possible?

Yes, because I understand that it is for use, not waste. That it costs money and should be used so as to produce all the heat it is capable of giving; which may be done by properly firing it.

5. (T-2) Do you earnestly try to do so?

I do.

6. (T-3) Why is smoke produced about stations objectionable?

Because it befouls the air, creates a nuisance and gets the Company into bad repute. And it gives evidence of poor firing, imperfect combustion and resultant waste.

7. (T-4) Can the labor of firing be lightened by intelligent management of the fire?

It can very much. By using **brains** in the exercise of good judgment, muscular exertion is lessened. Good work can be done by the Fireman in doing his part in generating steam. He should take pride in doing perfect work.

8. (T-6) Who handles the fuel?

The fireman does.

LESSON II.—QUALIFICATIONS OF ENGINEMEN.

9. (T-8) What is an engineer's or fireman's most necessary mental quality?

Good judgment. It correctly measures all conditions; speedily when necessary, and guides the fireman to do the **right thing** at the **right time.** It is not enough to KNOW because unless ALL the conditions that surround the work are taken advantage of and good judgment is used he will make blunders.

10. (T-8) Do you strive to always exercise it in your work?

The student **ought** to be able to answer most emphatically that he does.

11. (T-9) Name the ways in which engineers and firemen should co-operate to avoid waste and loss of fuel and unnecessary labor in firing.

Engineers should tell firemen about unusual stops to be made so that the fire can be regulated to save coal and both should co-operate and work together. Firemen should keep in mind what engineers tell them and act upon it, using their best judgment.

12. (T-9) Should you be careful about overloading your tender with coal at chutes and preventing the loss of coal overboard while running?

I should be and the engineer should co-operate. Unless there is harmony between us and we work well together it makes harder work for me. The engineer should tell me of all unusual stops so I can regulate the fire accordingly; and both of us should take care to prevent waste of coal at chutes, or while running.

13. (T-9) Why should you not permit long standing accumulations of coal on any part of your tender?

Because it loses heating value when exposed to air and weather. It should be often shoveled ahead and when used, replaced by fresh coal.

14. (T-10) What should be a fireman's attitude toward his engineer, and his engineer's instructions while on the road?

He should be willing to learn and profit by the experience and advice of his engineer. He should put into actual practice the best methods of work, as shown him by the engineer. He should always remember that the engineer is in full charge of the locomotive and that he is responsible for its condition, safety and performance. Therefore, while on a trip the fireman should respect his authority and carry out his instructions.

LESSON III.—THE FORMATION OF COAL.

15. Have you carefully read the description in this Lesson of the formation of coal?

Yes. And it is very interesting to learn exactly how a fire burns and to know **why** it burns.

16. (T-11) Was the earth always as cool as it is now?

No. It was once as hot as the sun now is. It was a fiercely burning mass of flaming gases—just exactly as the sun now is. In the course of ages and ages these flaming gases became liquids. White hot or red hot incandescent liquids which, after millions of years, gradually cooled. The terrific conflagration that raged for ages produced what nearly every ordinary fire produces—carbonic acid gas and steam —but in vast quantities. Almost every fire produces carbonic acid gas and water, but the heat converts the water into steam. So with the terrific fire of the earth ages and ages ago. The tremendous volumes of steam rising to the cold altitudes condensed to water and fell upon the earth's then incandescent crust in great downpours of rain. The rain immediately became steam again, rose to cold altitudes and again fell as rain. This was repeated over and over for ages, and helped to cool the gradually thickening crust, absorbed its heat and carried it away, until finally the crust was cool enough for vegetable and animal life.

17. (T-12) Does vegetation grow now as large and abundantly as it did when the world was younger?

It does not. Great trees grew four or five feet thick, almost branchless and of great height. They grew very fast, had a pithy interior, had very little strength as wood, but were good for coal formation. Heavy carbonic acid gas enveloped the globe, making human life impossible at that time. The crust was fissured and cracked with gaping openings from which poured great volumes of vaporous gases from the fiery interior. In this atmosphere vegetation grew in rank profusion. Some with stems two to three feet in diameter, like giant corn-stalks, grew forty to fifty feet above a great mass of huge ferns. There must have been perpetual summer, a continual blaze of tropical heat and sunshine, dense humidity and warm vapors, resulting in enormous growths of sappy vines, huge ferns, and resinous sticky weeds of tremendous size.

18. (T-13) What happened to vast quantities of trees and vegetation that first grew on the earth?

Whole forests were buried. For ages the earth's crust was comparatively thin so that the awful internal disturbance caused fearful earthquakes which rent the crust asunder burying great forests under sand and clay. These made new soil from which sprang fresh growths of trees and vegetation.

19. Name two ways in which this early vegetable matter was buried.

By internal disturbances causing fearful earthquakes. By the action of rivers carrying great quantities of drift wood and logs which were buried in the mud along the banks.

20. Describe in a general way how coal was formed.

The buried wood and rank vegetation became a soft black substance that retained all the elements of wood, but in a changed form. This was gradually compressed by the enormous pressure above it, caused by great rocks and vast quantities of soil, hundreds, sometimes thousands, of feet in depth.

The vegetation and great trees first became a soft, black substance then gradually became hard as it was pressed upon by the frightful pressure above, until, finally, it became coal.

LESSON IV.—THE COMPOSITION OF COAL.

21. (T-16) What substance forms the chief part of both anthracite and bituminous coal?

Carbon. It forms the chief part of all kinds of coal. It is the part that burns in the solid, or coke state, on the grates. It is the **coke** of coal and the **charcoal** of wood. Both forms are reached by practically the same process.

22. (T-16) What was this substance formerly?

It was carbonic acid gas of the atmosphere which passed into the form of wood as the vegetation grew and so became carbon.

23. (T-17 and 18) Which has the most "fixed" or solid carbon, bituminous or anthracite coal?

Anthracite coal. (It has about 85 per cent.) It also contains 5 per cent gaseous matter and moisture and 10 per cent ash. Thus Anthracite is almost all "fixed" carbon. That is why it burns on the grate in a solid state, with very little flame.

24. (T-18) Which has the most gaseous matter?

Bituminous. (It has 40 to 50 per cent.) It also contains 40 to 50 per cent of "fixed" carbon and about 10 per cent of incombusible matter (or ash). It is because Bituminous has about one-half gaseous matter that it burns **above** the solid fire of carbon as flame, or else produces smoke.

25. (T-18) What well known form of manufactured fuel does anthracite coal resemble?

Coke, which is made by heating coal in a retort from which air is excluded and permitting the gas to escape from it, leaving only solid carbon.

The following table shows the principal constituents of the coal used by the leading railways, the only percentages not shown in the table being made up of ash, moisture and sulphur:

	Average Fixed Carbon	Volatile Matter	Av. Heat Units Per Pound
Anthracite.			
Average of four districts.......	83.77	3.86	13,169
Semi-Bituminous.			
Average of six districts in Pennsylvania and W. Virginia	73.75	18.15	14,673
Pocahontas	74.39	21.00	15,070
Bituminous.			
Average of eighteen districts in Pennsylvania, Ohio, West Virginia, Kentucky, Tennessee, Illinois	52.25	34.75	13,000
Highest of above..............	60.99	32.53	15,200
Lowest of above..............	37.10	35.65	13,800
Illinois Bituminous.			
Thirty-seven districts	48.02	35.58	12,210
Iowa Bituminous.			
Five districts	37.47	38.44	13.400
Missouri Bituminous.			
Five districts	48.73	37.67	14,150

LESSON V.—HEAT.

26. (T-19) What is the Source of Power of all steam engines?

Heat. It is the only means by which water can be converted into steam, giving it all the power of EXPANSION it may have. It is only by its power to expand that steam is able to do the powerful work it does in the cylinders of an engine. It expands from a small volume at **high pressure** to a large volume at **low pressure.** Heat first produces steam from water, then as more steam is added high pressure is obtained, so HEAT is the source of steam power.

27. (T-20) What is a Unit of Heat?

The amount of heat required to raise the temperature of a pound of water (at 32 degrees F.) one degree. A pound of water is one pint. One unit of heat is just enough to warm a pint of water (at 32 degrees F.) one degree; two units of heat will warm it two degrees, or it will warm two pints one degree. Thus a hundred units will heat a hundred pounds (or pints) of water one degree, or it will heat one pint of water a hundred degrees.

An actual test, although somewhat crude, may be made by holding a lighted match under a thin metal vessel containing a pint (one pound) of water. It will heat the water two degrees, and it will produce two units of heat; therefore, one unit of heat is obtained by burning about half-a-match, or the amount of heat usually necessary to light a cigar.

LESSON VI.—THE COMBUSTION OF COAL.

28. (T-21) Man exerts his power over the world chiefly through what means?

Fire. It enables man to multiply his powers of production and transportation through the endless work of countless steam engines in shops and factories, on ships, in mines and on locomotives. Through the operations of FIRE the power of man is successfully exerted and maintained. We may be said to live by the aid of fire. Its power is converted into useful work, and this is accomplished through the processes of COMBUSTION.

29. (T-21) Is it, then, reasonable and necessary that firemen and engineers should thoroughly understand the burning of a FIRE?

It certainly is. Besides it is a very interesting and fascinating study, that may be easily understood.

30. (T-22) What is the air composed of?

Chiefly of two invisible gases: oxygen and nitrogen.

31. (T-22) The air is made up mostly of which gas—Oxygen or nitrogen?

Nitrogen.

32. (T-22) Which part of the air makes the fire burn?

It is oxygen that makes the fire burn. It is often called "the supporter of combustion," but as a matter of fact it is as much fuel of the fire as the coal. Apparently both are consumed in burning, but in reality neither is destroyed. Both combine—CHEMICALLY—to produce a new substance. The coal disappears as coal and the oxygen disappears as oxygen, but if the conditions permit a **perfect union** they reappear as CARBONIC ACID GAS.

33. (T-23) Which part of the air is inactive in the burning of the fire?

Although nitrogen is the larger part of the air, it is inactive in combustion (or burning). It does, however, hold back the activity of the oxygen.

34. (T-23) What would happen to a locomotive with a fire in its interior, if the whole of our atmosphere were oxygen?

It would burn up more rapidly than the coal. Because without the restraining power of Nitrogen iron would burn. It can be tested by a simple experiment. A piece of iron set light to in a jar of oxygen goes on burning to the end. Thus a fire burning on an iron grate burns ON it because of the nitrogen being there. If the air were pure Oxygen the grate would burn more fiercely than the coals, for the reason that under that condition the iron would be even more combustible.

LESSON VII.—THE COMBUSTION OF COAL —Continued.

35. (T-24) Name the two ways in which substances unite.

Mechanically and chemically.

36. (T-24) Describe the difference between a mechanical and a chemical mixture.

Substances united mechanically do not change. Substances united chemically combine and become a new and different substance.

37. (T-24) Is the combustion of coal a chemical or a mechanical combination?

It is a chemical combination. When the two gases known as Oxygen and Hydrogen unite chemically in the proportion of TWO atoms of hydrogen and ONE atom of oxygen the result is a fire—a very hot fire—which PRODUCES from the two invisible gases a new substance not like either of them; this new substance is—WATER. The difference between a chemical and a mechanical mixture is that substances mechanically combined **mix** with each other, but do not change. Whereas, in a chemical mixture they combine to produce a NEW substance. Thus if a piece of charcoal is heated red hot its particles or atoms will COMBINE CHEMICALLY with the atoms of the oxygen gas in the air and a hot fire is the result. The fire produces a new substance from the chemical combination unlike either the charcoal or the oxygen gas—known as: CARBONIC ACID GAS.

★38. (T-25) What difference is there in the amount of HEAT produced when carbon burns to CARBONIC ACID gas and CARBONIC OXIDE gas, respectively?

When carbonic acid gas is produced a pound of carbon yields 14,500 heat units. When carbonic oxide gas is produced it yields only 4,452 heat units per pound of carbon. Bituminous coal has about 50 per cent of gaseous matter which is composed chiefly of hydrogen, oxygen and nitrogen, and carbon vapor. These gases are liberated by the fire. If there is enough air to provide the oxygen required and if the temperature (bright red) 1,800 degrees F. prevails in the fire box, they are burned. This degree of heat is called "the temperature of ignition." The atoms from the coal and the atoms of oxygen have such tremendous attraction and they rush together with such fearful speed that they CLASH, and light and heat result from their clashing together.

TWO atoms of oxygen and ONE atom of carbon result in perfect combustion producing CARBONIC ACID GAS; but, when through insufficient air being supplied, ONE atom of oxygen and ONE atom of carbon unite, it results in imperfect combustion which produces CARBONIC OXIDE GAS.

39. (T-25) In combustion, which burns first—the gaseous or solid part of the coal?

The gaseous. The hydrogen gas separates from the carbon vapor and combines with the oxygen available (two atoms of hydrogen with one atom of oxygen)—and steam is the result.

In its turn the carbon vapor gives up ONE of its atoms to TWO atoms of oxygen and, in that proportion combines (chemically) with oxygen and is burned. It is in this way that the GASEOUS part of the coal is burned first.

40. (T-26) Does the burning of coal produce steam in the FIRE?

Yes. It does produce steam in the fire.

41. (T-26) If not, explain why. If so, explain how.

Steam in the fire is caused by the combination of two atoms of hydrogen gas with one atom of oxygen gas, producing the greatest heat known; and, strange as it may seem, also steam which condenses to water.

LESSON VIII.—THE COMBUSTION OF COAL —Continued.

42. (T-27) How hot must anthracite coal get before it will ignite and burn?

It must get red hot. It requires a higher temperature for ignition than Bituminous coal so it must be heated red hot because it contains but little gaseous matter. It burns with a short, transparent flame and makes but little smoke. Burns much like Bituminous coal burns after the gaseous matter has been liberated, because it is nearly all solid or "fixed" carbon.

43. (T-27) Which coal catches fire easiest, anthracite or bituminous?

Bituminous. Because of the easily ignited inflammable gases it contains.

The temperature of the firebox is one of the basic requisites of good firing. When the locomotive is properly fired and the consumption is at the ratio of about 20 pounds of air to each pound of coal the firebox temperature will be about 2,000 degrees F., the ideal temperature for perfect combustion. The ignition temperature of coal is between 1,800 degrees and 1,900 degrees F., and the maximum firebox temperature should be between 2,000 and 2,500 degrees F. The following shows the colors for the various degrees of heat:

1,300 degrees F.	Fire in dull red.
1,600 degrees F.	Fire in full cherry red.
1,850 degrees F.	Fire in bright red.
2,200 degrees F.	Fire in bright orange.
2,400 degrees F.	Fire in white heat.
2,600 degrees F.	Fire in welding heat.

44. (T-28) How does the burning of coal cause heat?

By the rushing together at tremendous speed of the atoms of oxygen and hydrogen, called "chemical affinity." The solid part of coal—both authracite and bituminous—is impure carbon. A diamond is pure carbon. If a diamond made fast to a loop of platinum wire is heated red hot in a flame and is then plunged into a jar containing oxygen gas it instantly glows like a little star, with a pure white light. It is caused by the atoms of oxygen striking against this diamond on all its sides. They are irresistibly attracted by CHEMICAL AFFINITY; an attraction of the same mechanical quality as gravity. Every oxygen atom as it strikes the surface has its motion destroyed by its impact with the carbon, and the motion produces the most intense HEAT. The attractions are so mighty that the brilliant gem is kept white-hot, and its atoms unite with the oxygen and fly away as carbonic acid gas. This experiment has been made and described by Professor Tyndall.

45. (T-29) Why does the breaking of coal into small lumps aid its burning?

Because of the greater surface it gives for the contact of the oxygen gas of the atmosphere. Only a two-million-three-hundred-thousandth part of the heat from the sun reaches the earth. Surely, a very small part! The **total** heat of the sun radiating from it in all directions is beyond our comprehension. How is its heat produced? Professor Tyndall says it is produced by meteors that shower down upon the sun exactly as the atoms of oxygen showered against the diamond burning experiment. Whether or not this theory is correct, there is a widely accepted theory that the heat of the sun is caused by BLOWS against it. In other words, meteors rushing toward it, drawn by its powerful attraction—just as bodies are drawn to earth by the attraction of gravitation—strike the sun with terrific force and generate its heat.

We know BLOWS produce heat. A nail on an anvil can be struck with a hammer until it becomes too hot to hold. Loose rods sometimes pound crank-pins and make them so hot that the babbitt metal is melted.

Coal in a furnace—after the gaseous matter has been expelled from it—is burned under similar conditions as the diamond in the jar was burned. The **speed** of combustion determines the degree of heat —its intensity or otherwise, and this, in turn, depends to a great extent upon the SURFACE of the coal against which the atoms of oxygen can strike. That is WHY coal should be broken to small sizes and spread over the fire to EXPOSE the largest possible SURFACE for contact with the oxygen of the air.

LESSON IX.—THE COMBUSTION OF COAL —Concluded.

★46. (T-30) What amount of air is required in practice for the burning of each pound of coal?

About 12 lbs. of air, or 150 cubic feet (at 32 degrees F.) is needed for perfect combustion, although in actual practice it is necessary to supply twice that amount in order to insure enough oxygen. One-fifth of the air is oxygen. This proportion is the same throughout the surface of the earth, whether high above it or deep below it. Therefore, a furnace can be provided anywhere with the needed amount of oxygen for the combustion of its fuel by arranging some means of drawing into it a known quantity of air; usually a chimney or stack.

47. (T-30) What is Natural Draft?

A chimney for drawing a known quantity of air to the furnace up from beneath and through the fire by the motion of an ascending column of hot air and gases.

48. (T-30) What is the cause of Natural Draft through a chimney?

Gravity, the force that pulls everything, including the air to the earth. Weight of any object is a manifestation of gravity. Air at sea level weighs about 15 lbs. per square inch. It is the result of this pulling force of gravity. When two liquids or gases are mixed together GRAVITY forces the lightest one to RISE through the mass of the heaviest one, so that gravity may pull down the heavier of the two. That is WHY oil rises rapidly **through** water and floats on its surface. Bubbles of steam, or gas, or air do the same. Air when it is warmed EXPANDS and takes more space than when it was cooler, because it is LIGHTER than before it expanded. When surrounded by cool air it RISES through the cool and heavier air. That is WHY mixed hot-air and gases in a chimney or stack RISE, leaving a partial VACUUM behind, causing the air below to rush in. That is HOW the NATURAL DRAFT through a fire and a chimney is caused.

49. (T-31) Is the natural draft sufficient to produce enough steam for a working locomotive?

No, it is not, when running. The natural draft acts upon the fire in a locomotive while the engine is not working, but while the engine is running great and intense heat is needed to make the steam used. To make this steam the water must boil very rapidly, because about half a barrel of water is converted into steam every moment while the locomotive is running, and sometimes when the load is very heavy, the traction poor, or the speed extra fast, a barrel of water every minute is often used to make steam.

50. (T-31) Is a stimulated draft necessary?

Yes, because of the continuous heat needed to boil the water rapidly. This heat is obtained by a fire surface of from twenty to forty square feet.

51. (T-32) If a stimulated draft is necessary, how is it obtained?

By the steam which escapes up the chimney (or stack) after it has done its work in the cylinders, commonly called the "exhaust." It creates a draft so strong and powerful that sometimes lumps of coal as large as walnuts dance up and down like drops of water on a red hot stove until finally they are burned, or else are reduced to the size of peas and then are driven through the tubes and shot from the stack like rockets.

52. (T-32) What is your understanding of an "exhaust" of a locomotive?

It is the steam that leaves the cylinder on both sides and rushing through the exhaust pipe shoots up the stack, making the noise called puffing.

53. (T-32) Is it your understanding that the

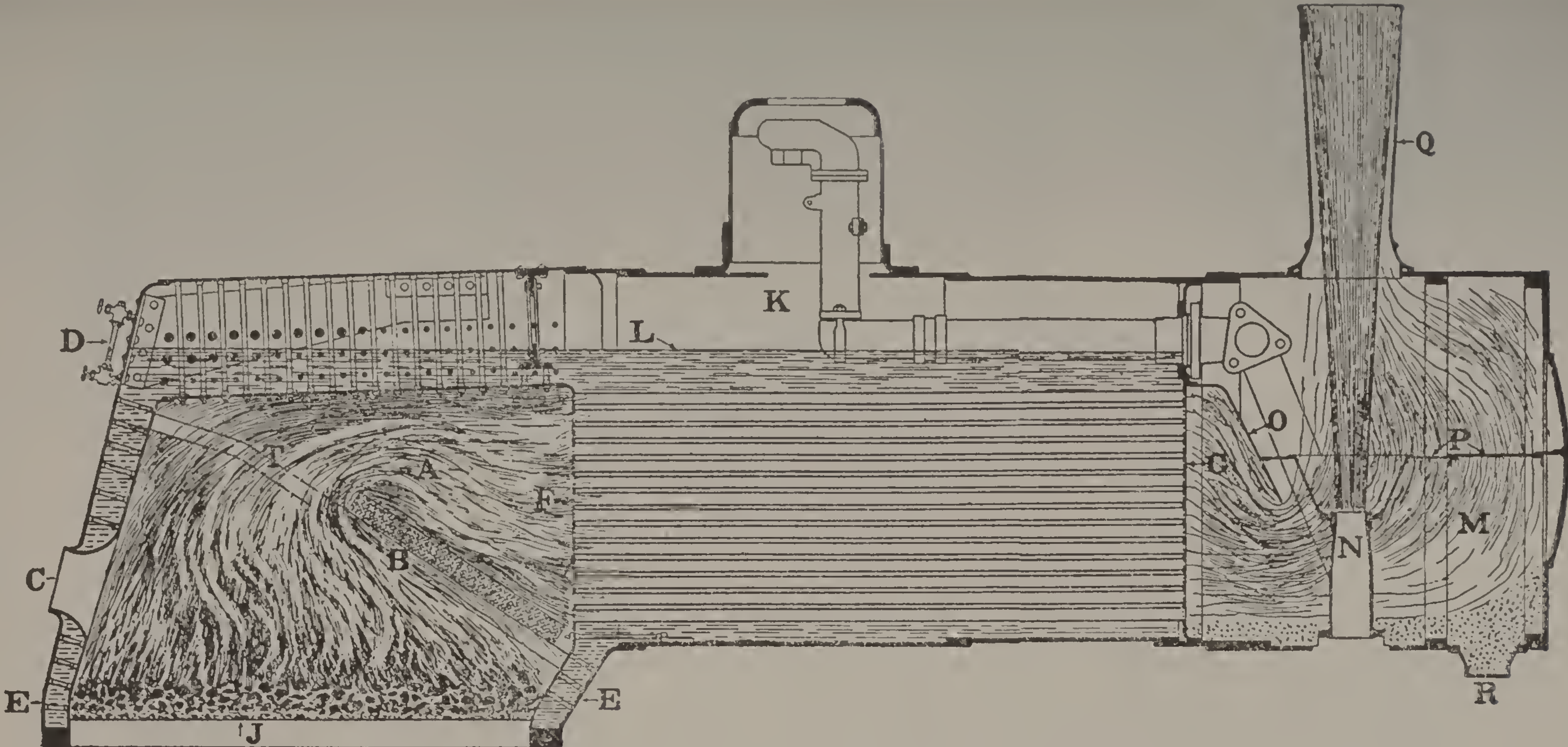


FIG. 1. LONGITUDINAL SECTIONAL VIEW OF A LOCOMOTIVE BOILER

SHOWING THE BOILER CUT IN HALF, LENGTHWISE

A Firebox, showing Combustion and Direction of Gases.
B Brick Arch.
C Fire Door.
D Water-Glass.
E Water-Legs.
F Back Tube Sheet.
G Front Tube Sheet.
J Coal Fire on Grates.
K Steam Space.
L Water-Level.
M Smoke Box.
N Exhaust Pipe.
O Deflector Plate.
P Netting.
Q Smoke Stack.
R Cinder Hopper.
T Arch Tube.

"exhausts" of a locomotive are a successive number of the same thing?

It is. It might be called a continuous endless number of liberated prisoners rushing to freedom after having been imprisoned and compelled to labor. The "exhausts" shoot up the stack with great force and rapidity in their rush to the atmosphere and freedom, but as fast as each "prisoner" is set free another one takes its place as it leaves the boiler to do its work and follow the others.

54. (T-32) Tell briefly and in your own way how the "exhausts" are made to produce the necessary draft through the fire, on a working locomotive.

The steam is contracted in its passage through the nozzle and so is given extra force and speed as it shoots up the exact center of the smoke stack. Ascending in a constantly expanding volume it creates a partial vacuum (or empty space) in the smoke box; this draws air through the grates and fire and tubes to the smoke box, the steam exhaust catches it and hurls it upward and a strong forced draft is caused. The illustration of a "Longitudinal Sectional View of a Locomotive Boiler," Fig. 1, explains this.

For example: When the throttle-lever is pulled it opens the throttle-valve in the stand-pipe. This pipe extends up into the dome. Steam is taken from the upper part of the dome so as to get as dry steam as possible—that is to say, steam without spray from the boiling water. From thence it is sent direct to the cylinders to expand and exert its force. Steam flows from the steam space (K) into the stand-pipe, then down the dry-pipe through which it reaches the front-end or smoke-box. Then it enters the steam-pipes, rushes down them to the steam passages in the cylinder-castings, to the steam-chests on top of the cylinders. Steam accumulates in the chests from which it rushes into the cylinders on either side of the locomotive by the movement of the valves. The illustration: "Sectional View Through Steam Chest

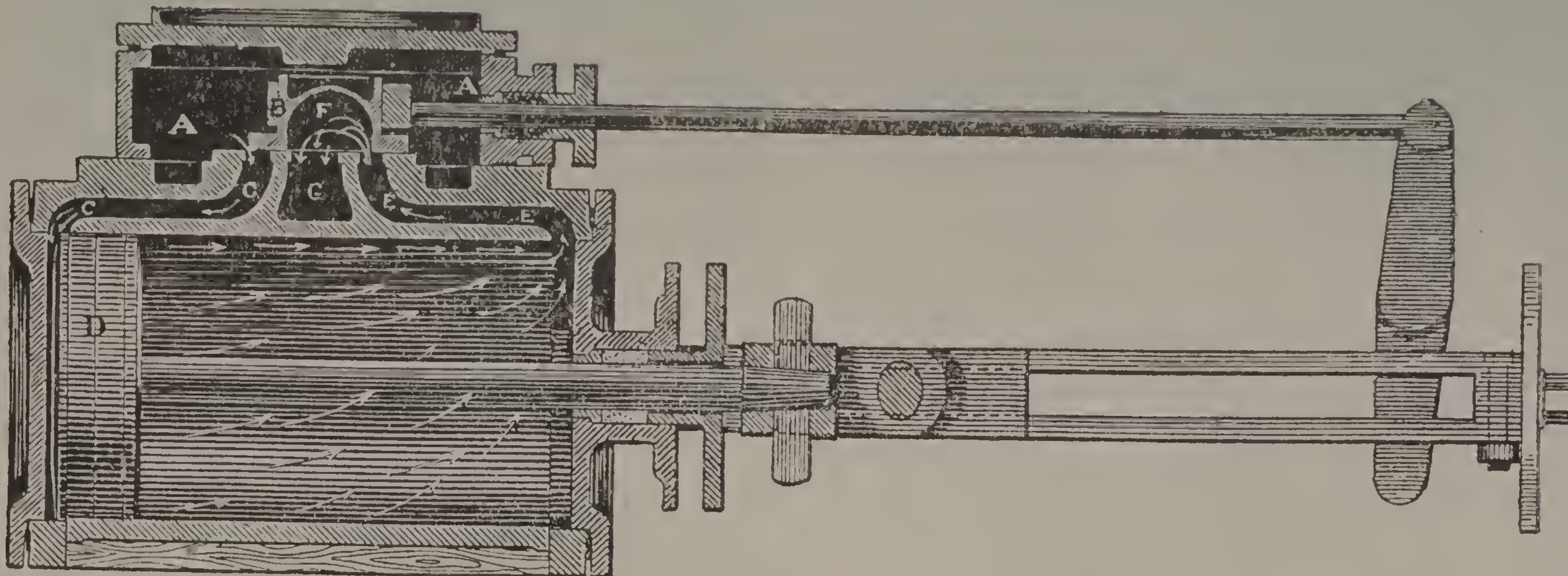


FIG. 2. SECTIONAL VIEW THROUGH STEAM CHEST AND CYLINDER.

Showing the piston, D, as having just completed a forward stroke, and ready to begin a backward stroke.

NOTICE that the valve, B, is moving backward, and is allowing *exhausted* steam to *escape* from the cylinder through the back steam-port, E E, to the exhaust-cavity in the valve, F, thence into the exhaust-passage, G, and thence to the exhaust-pipe in the smoke-box.

NOTICE also that the valve, B, is *beginning* to *admit* new live steam from the steam chest A, A, to enter the cylinder *in front* of the piston through the front steam-port, C, C; thus commencing the backward stroke.

and Cylinder" (Fig. 2) shows the inside arrangement of a steam-chest and cylinder. Imagine it to be cut length-wise, through the center. AA is the space inside the steam-chest, full of live steam just from the boiler, ready for admittance to the cylinder. D is the piston just completing a forward stroke. The valve gear mechanism is so arranged that slide-valve B is now being pulled backward, its front edge uncovering the front-steam-port opening, steam is entering steam-port CC, is flowing to the cylinder wherein it will push the piston backward. That is HOW steam reaches the cylinder and does its work. Next is shown HOW steam leaves the cylinder and WHAT it does after leaving. (See Figs. 3 and 4.)

The arrows in the illustration are intended to show the movement of the steam that pushed the piston forward when completing the stroke as shown. Through the position of the valve B this steam,

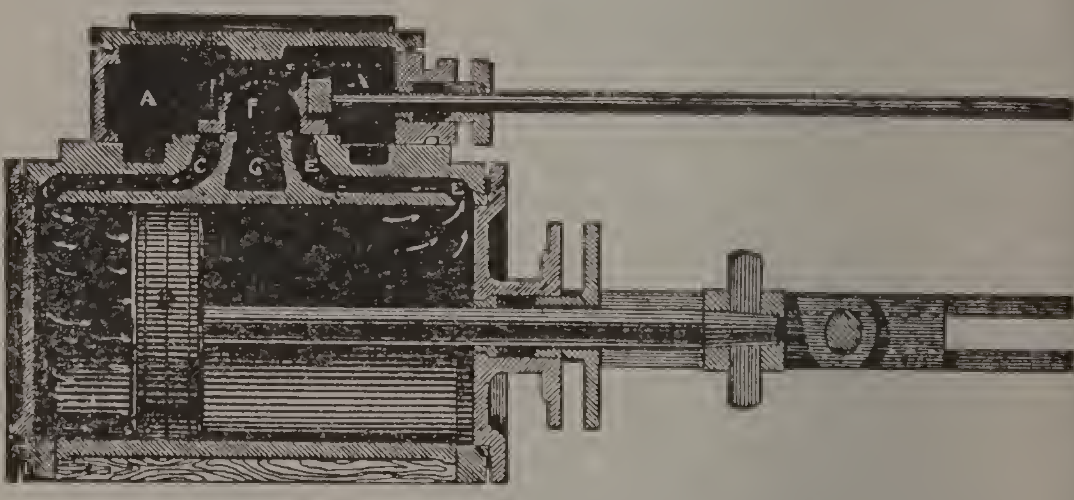


FIG. 3. SECTIONAL VIEW THROUGH STEAM CHEST AND CYLINDER.

Showing action of exhaust steam in leaving the cylinder.

now being exhausted, escapes the way it entered the cylinder EE to the exhaust-cavity in the valve F, then into the exhaust-passage G, through which it rushes to the exhaust-pipe shown in AA. The illustration "Sectional View of Locomotive Smoke-Box and Stack" (Fig. 4) shows this steam rushing up the smoke-stack to the atmosphere. These escaping "cylinder-fulls" of steam rushing upward with great speed, one after the other, cause the report called "puffing," of which there are sometimes many in a second. Each "puff" represents a "cylinder-full" of escaped steam that has gone through several movements in doing its work, and even as it rushes away it is made to serve a purpose in creating A FORCED DRAFT.

The illustration (Fig. 4) shows a LOCOMOTIVE FRONT-END ARRANGEMENT, consisting of the smoke-stack, smoke-box and exhaust-pipe and nozzle; cut in half, straight up and down. BB shows the ends of the exhaust-passage leading from the right and left cylinders. AA is the exhaust-pipe into which the steam "exhausts" from the cylinders on either side are admitted, to be directed upward to the EXACT CENTER of the smoke-stack. Finally they are contracted in their wild rush to escape, because they are forced to pass through the nozzle N. This contraction gives them extra force and greater velocity (or speed) to perform their last work as they shoot up the stack.

The artificial or "forced draft" thus created is regulated in its effect upon the fire by the work the engine does. Light work requires less steam than heavy work. When but little steam is used the exhausts escape softly and create a light draft. Heavier work uses more steam, and the larger amount exhausted creates stronger drafts.

55. (T-33) What is meant by "rate of combustion?"

The weight of fuel burned on each square foot of grate surface in an hour.

56. (T-33) Is the very rapid burning of coal economical or wasteful?

It is very wasteful. Coal is burned rapidly when there is not enough TIME allowed for the union

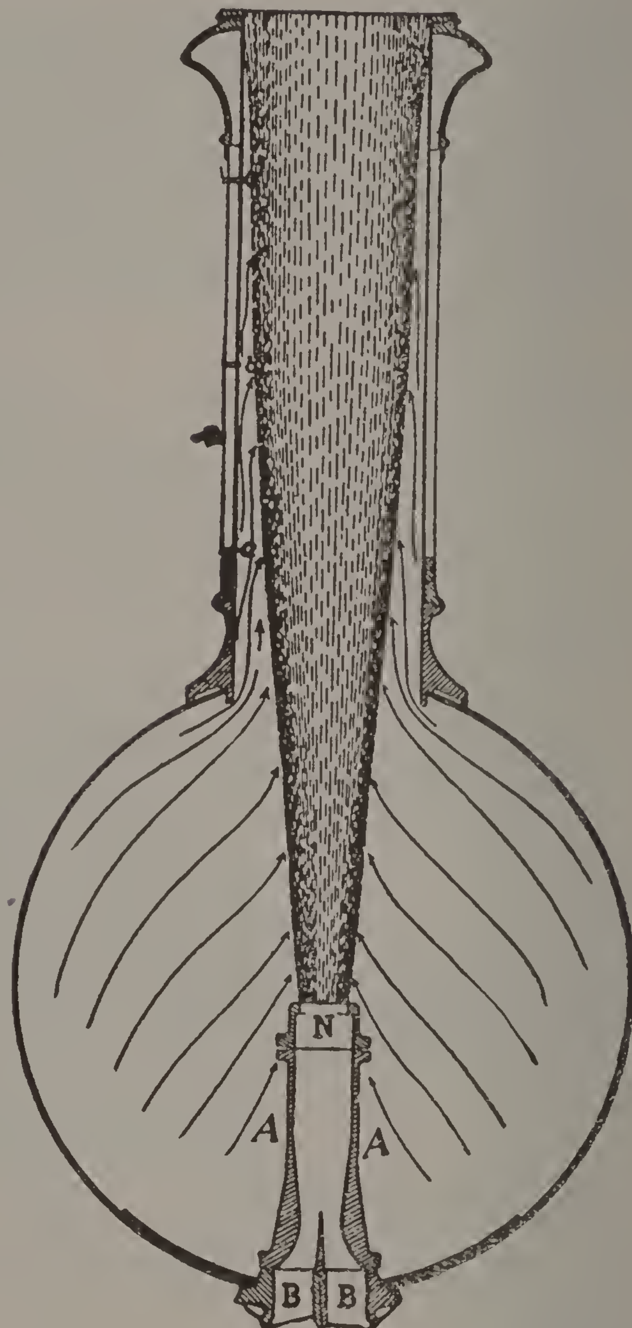


FIG. 4. SECTIONAL VIEW OF LOCOMOTIVE SMOKE-BOX AND STACK.

Showing the action of exhaust steam in escaping up the smoke-stack. Determined by tests conducted by a committee of the American Railway Master Mechanics' Association.

of the atoms to produce perfect combustion. The gaseous portion of coal, especially needs TIME. If not given time it escapes as dense smoke and is needlessly wasted. There must be enough time to supply sufficient air as well to the coal burning on the grates. The RATE OF COMBUSTION should be as LOW as possible.

57. (T-33) Which should a fireman do—aim to keep his "rate of combustion" as high or as low as possible, while supplying sufficient heat for keeping up steam?

He should keep it as low as possible, without reducing the regular boiler pressure.

58. (T-34) What is the "blower" used for?

To create draft for the fire while the engine is standing.

59. (T-34) Explain briefly how it causes a draft through the fire.

It is caused by a small admission of steam through the blower pipe to nearly the tip of the exhaust nozzle. It causes a draft the same as the exhausts do, but much milder and steady.

60. (T-35) Describe the proper use of the blower in raising the steam pressure.

It should be used as lightly as the time needed to raise steam will permit.

61. (T-35) Describe the proper use of the blower in working at the fire.

It should be operated so as not to cause too rapid a rate of combustion.

62. (T-35) If the steam pressure is increased, is there any change in the temperature of the boiler?

Yes, the temperature is increased. It is important to increase the temperature gradually, because of the increase of boiler temperature as the steam PRESSURE is increased. For example: when the steam pressure is increased from 50 to 100 pounds the temperature of the boiler is increased 40 degrees, or almost one degree for each pound of pressure increase.

It is because the BOILER EXPANDS when heated, that the rapid increase of steam pressure causes damage to boiler plates and stay-bolts, because the rise in boiler temperature causes a too sudden expansion. On the other hand there is a corresponding fall in temperature with a decrease of steam pressure. That causes the boiler to COOL and CONTRACT. "Expansion" and "contraction" is the same as stretching and shrinking. These movements do damage to locomotive boilers. Hence it is important to always keep the steam pressure as steady as possible.

63. (T-35) What change, if any?

If the steam pressure is increased from 50 to 100 pounds it increases the temperature of the boiler 40 degrees. Sudden increase of boiler temperature causes expansion and grave danger to stay-bolts and plates.

64. (T-35) If the steam pressure falls, is there any change in the temperature of the boiler?

Yes; sudden cooling causes a lower temperature.

65. (T-35) What change, if any?

It causes contraction of the boiler and its parts.

66. (T-35) In what way does changing steam pressure injure a boiler?

Cracking of plates, breaking of stay-bolts, leaking flues and damage to flue sheets.

LESSON X.—FIRING WITH BITUMINOUS COAL.

67. (T-36) On what does the fire in any furnace rest?

The grates which serve as its foundation.

68. (T-36) Are the grates of much importance in a fire-box?

Yes, they are of vital importance, because fire is the life-giving power to an engine and upon the grates rests the source of the locomotive's power; and they should receive proper inspection and handling.

69. (T-36) Name the two most important duties of a fireman concerning his grates which must be attended to before starting.

He must see that the ash pan is clear of ashes and that the grates are all level and connected.

70. (T-36) Should grates be kept level, or otherwise?

They should be kept level.

71. (T-36) What may happen to the grates if they are not kept level?

Some of the fingers of the grates might project into the fire and be burned off. Lumps of clinker might get wedged between fingers, allowing red-hot coals to fall into the ashpan to burn out the grates bodily.

72. (T-36) When should a fireman be careful to place or lock his grates in a level position?

Every time he moves the grates.

73. (T-36) Describe a fireman's proper inspection of his grates and ashpan before starting on any trip.

He should get down from the engine and look carefully into the ashpan. He should notice whether each bolt that connects the grates is in place. Should any defects be found they should be reported before starting out.

74. (T-36) How should this inspection be made?

Before starting on any trip.

75. (T-37) Why should the grates be shaken while running?

To prevent a thick bed of ashes or clinkers from forming to exclude the air from the fire.

76. (T-37) The grates should be shaken about every—how many miles on freight engines?

About every twenty miles.

77. (T-37) On passenger engines?

About every thirty miles.

78. (T-37) When is the best time to shake the grates?

When steam is shut off, or when draft through fire is light.

79. (T-37) What would be the results if the grates were shaken too much?

Smoke and cinders or unconsumed coal would be shot out the stack. This is wasteful. The best results are to be had by shaking the grates just enough to shake the ashes into the ash-pan. It is only necessary to give free passage through them for air to reach the fire.

80. (T-38) How are clinkers formed in the fire?

By the accumulation of ashes that melt together.

81. (T-38) How do they affect the fire?

They prevent perfect combustion.

82. (T-38) How can the formation of clinkers be partly prevented?

By frequent shaking of the grates.

83. (T-38) What must be done with clinkers when they prevent the easy steaming of an engine?

They must be removed by hooking out or knocking out as soon as possible. A good time to do it is when the train has a ten or fifteen minute wait, or while train is not using steam on a long down grade run.

84. (T-38) Should clinkers be hooked or knocked out while the engine is using steam?

No.

85. (T-38) Why?

Because cold air would rush in while doing so and causing sudden contraction might do damage to boiler plates, tubes and tube sheets.

86. (T-38) In discharging clinkers from an engine, in regard to what matters of safety must special care be exercised?

To see there is no chance for them to strike any person or to fall on or near any bridge or culvert.

87. (T-38) Ash pans and fires MUST NOT BE CLEANED near what places?

Bridges, culverts, depots or buildings.

88. (T-38) What part of the grates should clinkers be banked on, if there is no time or opportunity to hook or knock them out?

At the back of the firebox.

89. (T-38) Why this part?

Because there they do least harm in keeping air from the fire and when the chance comes can be quickly got rid of.

90. (T-38) Should clinkers be worked at from the top or from the bottom of the fire?

Always from the top of the fire.

91. (T-39) When coal is burning—What is necessary to make it give off the most heat?

Sufficient air.

★92. (T-39) In burning PERFECTLY, a pound of coal will make enough heat to evaporate how many pounds of water?

About twelve pounds of cold water.

★93. (T-39) In burning IMPERFECTLY a pound of coal will make enough heat to evaporate how many pounds of water?

Four pounds of water. Imperfect combustion makes two-thirds less heat than perfect combustion does from the same number of pounds of coal. Thus less water is turned into steam.

94. (T-39) Which is the most necessary "fuel" for the fire—coal or air?

One is as necessary as the other, because both burn and help to make heat.

★95. (T-39) About how many box-cars full of air must pass through the fire usually, to PROPERLY burn each charge of about four shovelfuls of coal?

About eight box-cars full.

96. (T-39) What condition should the bed of fire be in for the proper admission of sufficient air?

Uniform in depth and in condition so air can get through it easily to the fresh coal on top of the bed.

97. (T-40) Can too much air be admitted to the fire?

Yes, because all air admitted over and above the quantity needed for perfect combustion absorbs the heat of the fire and carries it away.

98. (T-40) What is necessary to guard against access of too much air?

The full grate surface must be kept covered with fire. There must be no air holes, dead spots or bare spaces.

LESSON XI.—FIRING WITH BITUMINOUS COAL—Continued.

99. (T-41) How long before leaving time should a fireman go on duty?

At least 30 minutes.

100. (T-41) When should he examine the condition of his fire?

When he mounts his engine before going out.

101. (T-41) In case the grates are not entirely covered with live fire—what should be done?

Fresh coal should be put in and the grates completely covered with live fire.

102. (T-41) What should be seen to about the grates and ash pan?

That tube sheets are free from honeycomb or clinker, ashpan clear of ashes and grates all level and connected.

103. (T-41) What should be seen to about the smoke-box?

That it is clear of cinders.

104. (T-41) What should be seen to about the tube sheet?

That there are no clinkers there.

105. (T-41) At leaving time the steam pressure in the boiler should be at what point?

As nearly as high as allowed.

106. (T-41) At leaving time, the water level in the boiler should be at what height?

As full as permitted. Usually three full gauges.

107. (T-41) What about the inspection of the engine before leaving?

It should be thorough, and it is important, because it often prevents engine failures and delays on the road.

108. (T-42) Briefly describe the proper condition of the fire, steam pressure and water-level when the engine is ready to start.

The fire should be level over all the grates and have a good bright bed. The steam pressure should be nearly as high as is permissible. The water level should show the boiler to be as full as allowable, usually indicated by the water glass being three-fourths full.

109. (T-43) Should the fire-box door stand OPEN, or CLOSED, while the engine is starting?

Closed, or on the latch.

110. (T-43) Why?

To prevent the chilling effect on the boiler that would result if the door were wide open for an in-rush of cold air. The door should be closed or put on the latch before the first steam exhaust escapes. The small opening in the door allows air enough to be drawn into the firebox to offset the "tearing of the fire" the strong draft produces. This results in fuel economy and prevents boiler injury.

The fire should be in and the fire door closed or put on the latch every time before starting. On passenger engines, with light trains it is not always necessary to put in more coal before leaving every station. But on freight engines the coal put in before starting should be enough to last until the engine is put to working at a short cut-off.

111. (T-44) Should a fireman pay attention to the height of the water-level in the boiler and the engineer's habits of operating the injector?

Yes, he should pay particular attention.

112. (T-44) Supposing that the engine has run a mile with the injector suspended—should a "fire" be put in before or after the injector is started?

Before.

113. (T-45) How should a fireman think and act concerning coming conditions of work?

He should "anticipate" or think ahead of his work.

114. (T-45) What condition should the fire be in when the steam is shut off?

Neither low or fierce. Medium hot.

LESSON XII.—FIRING WITH BITUMINOUS COAL—Continued.

115. (T-46) Except in emergencies requiring full boiler pressure—should the fire be forced to rapidly regain lost pressure?

It should not.

116. (T-47) In a fire needing more coal—which places should first be covered with fresh fuel—places at a white heat, or places that have burned down to red?

The red places must be first covered and next the bright or white places.

117. (T-47) Describe briefly and in your own way the proper condition of the fire while running to produce the greatest heat with the least fuel.

There should be a good bed about three or four inches deep, heavy at the corners and along the sides. The top of the middle portion level and the whole fire bright and white all over.

118. (T-47) Is this the condition you try to keep your fire in?

The student should be able to answer that it certainly is.

119. (T-48) Does it make much difference if in the bed of fire there are several square feet on which not much coal is burning?

It does.

120. (T-48) Should every square foot of the fire's surface be made to do its share of work?

It should.

121. (T-48) On what part of the fire does the draft usually act strongest?

In the corners and along the sides.

GRAPHIC ILLUSTRATIONS OF DIFFERENT WAYS OF THROWING COAL INTO THE FIREBOX.

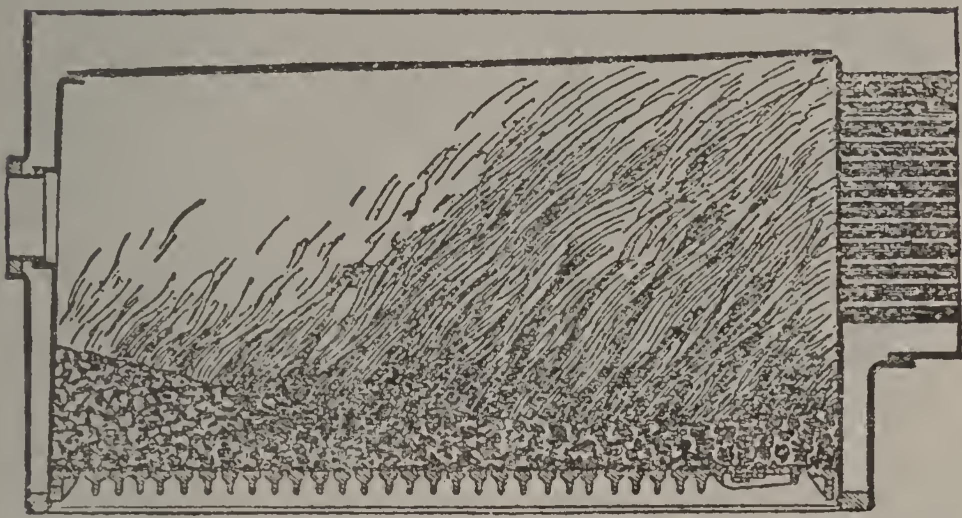


Figure No. 5 shows the system of Heavy Firing at the Furnace Door, resulting in a Bright Fire over a portion only, with a consequent reduction of Fire Box Temperature.

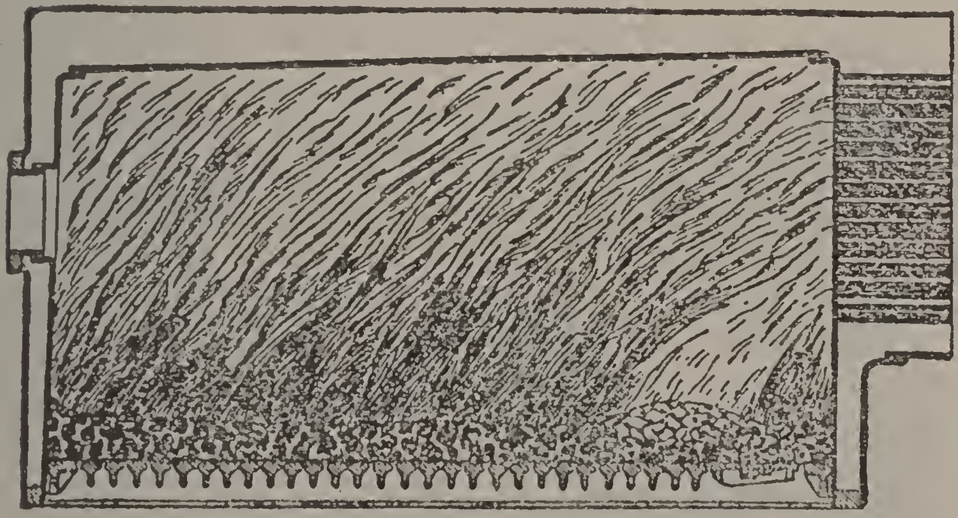


Figure No. 6 shows a system of Shallow and Level Cross Firing with slight building up around the edges, producing a Bright Fire throughout, with High Temperature within the whole Fire Box.

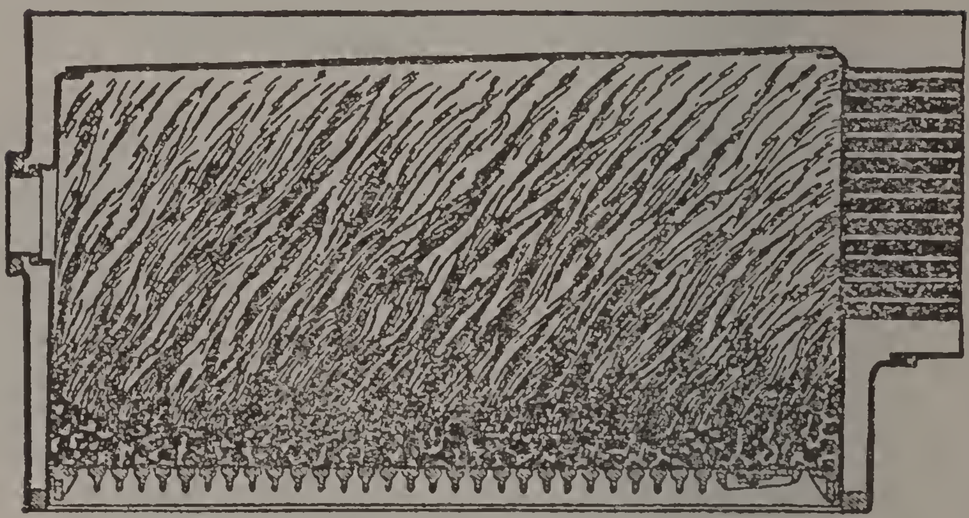


Figure No. 7, shows the effect of the temporary reduction in Fire Box Temperature when a shovel of coal is introduced.

Figure No. 8, shows the reduced temperature restored at the time the second shovelful is introduced, as would be the case with the system of Cross-Firing.

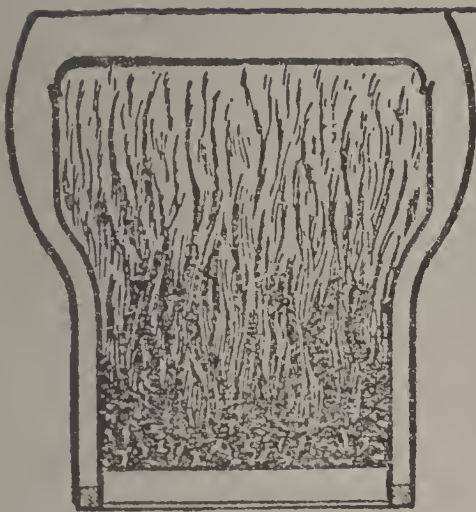


Figure No. 9 shows the piling of the coal on the side as would be the result of Cross-Firing.

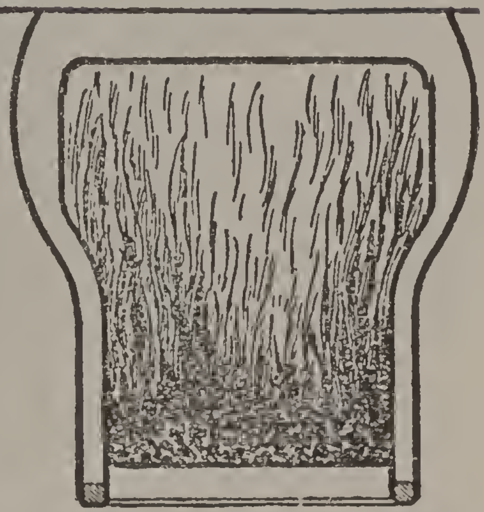


Figure No. 10 shows the action of the draft in thinning fire along the walls of the Fire Box and the edge of fire unless piled, as per figure No. 5.

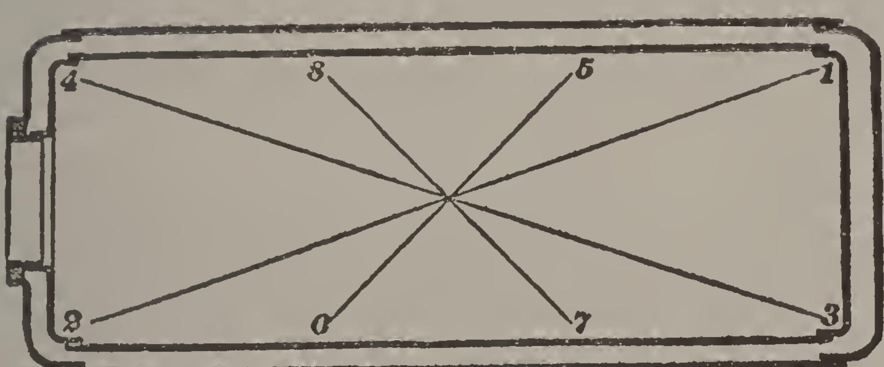


Figure No. 11 shows the method of Cross-Firing as indicated by successive numbers on the arrows, first firing on one side and then the other, along the walls of Fire Box.

122. (T-48) How should the coal be placed on the fire—in a heap, or evenly and lightly spread?

Evenly and spread lightly all over.

123. (T-49) What is a "bank" in a fire?

A sure proof of poor firing. It is caused by putting more coal on some portion than it can immediately burn. Coal that should have spread over ten or fifteen square feet has been carelessly dumped in to cover only three or four square feet.

124. (T-49) How is it caused?

By carless firing.

125. (T-49) Who is responsible for it?

The fireman.

126. (T-49) Is it good for steam making?

It is not.

127. (T-49) How does it affect steam making?

It retards quick steam making.

128. (T-49) Does it add greatly to the heat being produced by the fire?

It does not. A bank of unburned coal acts much like a blanket. It serves to prevent combustion. It practically puts out of action all the fire surface it covers. It is an enemy of economical use of fuel and prevents quick steam making.

129. (T-49) If so explain how, and if not explain why.

During the time the fire's surface is covered or smothered by a bank the other portions have to do more than their proper amount of work and that causes too rapid combustion and results in loss. A bank in the fire often starts a clinker formation.

130. (T-49) What should be done with banks?

Broken up and spread out with the hoe to burn.

131. (T-49) Should more coal be put on banks before or immediately after they are spread?

No, not more coal, but more time is needed.

132. (T-50) Describe perfect firing.

Perfect firing is to fire lightly and spread evenly, putting in one shovelful at a time, placing each in a different place, alternately. Using good judgment regarding where to put coal on the bed according to its appearance and according to the work the engine has to do. The coal should be well broken.

133. (T-50) Ordinarily how many shovelfuls of coal should be put in per "fire?"

Properly only one, never more than two.

134. (T-50) Why does this method produce the best results?

It causes less smoke and makes a steady steam pressure with less coal than when larger charges are put in.

135. (T-51) To what size should lumps of coal be broken?

About the size of ordinary apples.

136. (T-51) Why does breaking coal into small lumps aid its burning?

Because there is more surface thus exposed to the action of the oxygen of the atmosphere, which assists rapid burning and the production of intense heat.

LESSON XIII.—FIRING WITH BITUMINOUS COAL—Continued.

137. (T-52) Describe heavy firing.

It is throwing in too much coal at a time.

138. (T-52) What are its results?

Shuts off air, cools the fire, lowers the temperature of the boiler.

139. (T-52) Why are these wasteful and damaging?

It causes imperfect combustion. Gases escape up the stack without having yielded heat units, causing wasteful loss. The contraction of the boiler parts due to reduced temperature causes damage to tubes and tube sheets or to staybolts because there is a sudden expansion or stretching when the big charges finally begin to burn fiercely.

140. (T-53) Should a "fire" be put in hastily or leisurely?

Leisurely.

141. (T-54) Is "pulling" the fire an unavoidable accident, or is it the result of carelessness and neglect?

It results from carelessness and neglect.

142. (T-54) Who is to blame?

Both the engineer and fireman. It is very harmful to have a fire "pulled" by heavy exhausts when starting. Such mishaps cause serious delays to trains. It should be prevented by being everlastingly on the watch to keep the fire in good condition all the time.

143. (T-54) What treatment is necessary to restore the fire to proper working conditions?

The fireman must notify the engineer who will at once ease off the steam. If steam must be used the dampers must be immediately closed and the fire door put on the latch. Then coal enough to hold the fire without smothering it must be put in. The door again put on the latch and the blower used to build up the fire. While the exhausts are heavy the dampers must be kept shut to prevent the strong blasts of air from going through the fire.

144. (T-55) How much coal is usually wasted when the safety-valve operates?

A quarter pound each second.

★ **145. (T-55) With coal costing $2.50 per ton, estimate the loss of coal and money when an engine pops sixty-two times a day—for a month.**

It amounts to about 8 tons of coal, which would cost $20.00. This shows how important it is to keep an even steam pressure while the locomotive is running. Changes of pressure interfere with the proper working of the engine. So while sufficient steam pressure should be maintained, yet no surplus steam should be generated to blow away through the "pop" or safety valve without having done any work and resulting in loss of fuel needlessly burned.

146. (T-56) How can "popping" be prevented?

By the exercise of good judgment in so feeding the fire according to the work to be done as to keep an even steam pressure.

147. (T-56) What evil results follow from a wide-open fire-door when the engine is working?

The howling "pop," indicating carelessness and bad judgment.

148. (T-56) Why does dropping the dampers decrease the heat of the fire?

It temporarily suspends combustion.

LESSON XIV.—FIRING WITH BITUMINOUS COAL—Concluded.

149. (T-57) Why are wide fire-boxes used?

To give more grate surface and permit of a softer draft.

150. (T-57) Should wide fire-boxes carry deeper or thinner fires than narrow fire-boxes?

Thinner fire-beds.

151. (T-57) Should a fire in a wide fire-box be "fired" more heavily or more lightly than in a narrow fire-box?

It should be fired more lightly.

152. (T-58) What is smoke?

A mixture of gases and carbon.

153. (T-58) Why is smoke about depots objectionable?

It annoys patrons of the company and is regarded as a nuisance.

154. (T-58) How can it be prevented at such places?

By building up the fire gradually—scattering one or two scoopfuls of fine coal over the surface and with the door ajar or blower on a little, if needed, give time for the gas to escape and burn before putting more coal in.

155. (T-58) Why is smoke objectionable when trailing back over trains after steam is shut off?

It annoys passengers—and on freight trains obscures the vision of the trainmen.

156. (T-58) How can it be prevented at such times?

By opening the fire door and using the blower as much as necessary.

157. (T-59) Is "drumming" a desirable noise about passenger trains?

It is not.

158. (T-59) How can it be prevented?

By closing one or both dampers, or opening fire door enough to stop it, whichever seems to accomplish it best.

SECOND EXAMINATION

ECONOMICAL BOILER-FEEDING

LESSON XV.—IMPORTANCE OF BOILER-FEEDING.

159. (T-61) What is an engineer's first duty?

To be always watchful and anxious for the safety of his engine and train.

160. (T-62) What is the most important part of a locomotive?

The boiler.

161. (T-63) What is the most important phase (or matter) of locomotive management?

Boiler feeding.

162. (T-62) Within what limits should the steam pressure be kept while running?

Within the limits of about ten pounds.

★163. (T-63) What is the difference of temperature between steam of 100 and 245 pound pressure?

There is a difference of 66.5 degrees because at 100 pounds steam pressure the temperature is 338 degrees while at 245 pounds steam pressure the temperature is 404.5 degrees.

164. (T-63) What effect does a very high temperature have on boiler plates?

It rapidly weakens them.

165. (T-63) How do locomotive boiler explosions occur? In connection with this question study the following table.

Through some portion of the heating surface becoming bared to the heat of the fire while under pressure. In a very short time the metal becomes heated and weakened enough to give way under the heavy pressure upon it. Weakening starts when wrought iron or steel boiler plates are heated above 400 degrees, which is the temperature of steam at 235 pounds pressure. When the temperature is raised above 400 degrees weakening goes on very rapidly, increasing with the temperature until the plates melt. When a thousand degrees hot their strength is reduced eighty per cent, or four-fifths, so they would have only one-fifth the strength they had at temperatures between zero and 400 degrees.

When water completely covers the heating surface of a boiler it is safe to assume there is no danger of overheating, as it is not likely the steam pressure will rise above 250 pounds. But with a hot fire and a bare crown-sheet it might take only ten or twenty seconds to heat the metal so that it would give way to the heavy pressure. For with 150 pounds working pressure there is over ten tons pressure to EACH SQUARE FOOT of the crown-sheet. From that cause many locomotive boiler explosions have occurred according to authorities.

TABLE SHOWING VARIATION OF TEMPERATURE OF BOILING WATER AND STEAM ACCOMPANYING VARIATION OF PRESSURE.

Effective pressure per square inch.	Temperatures.	Effective pressure per square inch.	Temperatures.
Pounds.	Degrees.	Pounds.	Degrees.
Atmospheric pressure 0	212	110	344
10	240	120	350
20	259	130	355
30	274	140	361
40	287	150	366
50	298	160	370
60	307	170	375
70	316	180	380
80	324	205	390
90	331	235	401
100	338	245	404.5

166. (T-64) Is the work of locomotives very similar to stationary and marine engines?

It is not.

167. (T-64) How does the work differ?

Stationary and marine engines have an almost constant steady amount of work to do. Locomotives have a constantly changing, irregular amount of work to perform.

168. (T-64) Should the method of feeding locomotive boilers be similar to the usual method of feeding stationary and marine boilers?

No, it should not.

169. (T-64) Describe good locomotive boiler-feeding.

Locomotives should have water fed into their boilers while running into stations, or going down grades with steam shut off. Also while at a standstill. The water should be injected with care and good judgment as to the amount so as not to cause too much variation in steam pressure, also to avoid priming.

170. Describe your method.

The student should be able to answer as follows: Starting with the glass two-thirds full, I shut off injector for half mile or a mile. Then with half a glass of water, the engine working easily and train running fast, I start injector again.

LESSON XVI.—BOILER-FEEDING—Continued.

171. (T-65) What is meant by the term "atmospheric pressure?"

The pressure (or weight) of the air of the atmosphere at the level of the sea.

★172. (T-65) At what temperature does water boil under atmospheric pressure?

212 degrees.

★173. (T-65) What is the weight of the air per square inch at sea level?

14.7 pounds, but usually figured as about 15 pounds.

174. (T-65) The "boiling point" of water depends upon what condition?

The pressure upon the water.

175. (T-65) When water boils, which is the hottest—the water or the steam that comes from it?

One is as hot as the other.

★176. (T-65) When cool water is turned into steam of high pressure, what proportion of the necessary amount of heat to do this must be put into the water to RAISE it to the "BOILING POINT?"

One-third.

★177. (T-65) Then what proportion of the total necessary heat is required to TURN the boiling water INTO STEAM?

Two-thirds.

178. (T-65) Are these facts of much importance in locomotive boiler-feeding?

They are of utmost importance.

★179. (T-66) With an ordinary "wagon-top" boiler how much water can be held in the space within the boiler indicated by the water-glass?

400 gallons.

★180. (T-66) How much water can be held in the space indicated by one inch of the water-glass?

Forty gallons.

★181. (T-66) How much heat can we store in this last named quantity of water?

All the heat units yielded from an ordinary shovel of coal properly burned to secure perfect combustion.

★182. (T-66) How much heat can we store in the first named quantity of water?

All the heat obtained from the proper combustion of ten ordinary shovelfuls of coal.

183. (T-67) Is such stored heat within the boiler of any advantage?

It is.

184. (T-67) How can it be used to save coal?

It serves as a reserve or storage of heat to be drawn upon when there is extra hard work for the engine to do demanding an extra amount of steam. It then is not necessary to force the fire or use the injector and in that way coal is saved.

185. (T-67) Why does an engine make steam more easily with the injector shut off than with it in operation?

Because a third less heat is required from the fire than would be needed were the injector feeding in as much water into the boiler as is being used in steam.

186. (T-67) When is the best time to put water into the boiler?

When the desired pressure is regained. It could be worked finer if good judgment dictated until a favorable time for harder work.

187. (T-67) Why is it economical to reduce the rate of combustion?

Because more pounds of water per square foot of grate surface per hour can be turned into steam from each pound of coal burned.

188. (T-67) What must you be careful about regarding the steam pressure when filling the boiler with water?

To keep up an even, steady steam pressure.

189. (T-67) Why is it necessary to keep the steam pressure steady?

To prevent the contraction or expansion of the metal of the boiler and so avoid unnecessary damage.

190. (T-68) When the water in the boiler is up to the working limit, how can surplus steam be stored?

By opening the injector throttle and tank valve and allowing the excess steam to blow back into the tank.

LESSON XVII.—BOILER-FEEDING—Concluded

191. (T-69) Should the injector ordinarily be permitted to inject more water than is being used as steam while running along normally?

It should not. If more water than is being used as steam is injected into the boiler while the locomotive is doing ordinary work, particularly when running along a level track, much coal is wasted as a result, because the fire then has to be forced to give more heat than is needed.

192. (T-69) Is it better practice to have it supply a little less water than is being used as steam at such times, if practicable?

Yes. The injector should be adjusted to supply slightly less water than needed to replace the water being used, provided the boiler is full enough to permit it, then when the engine is next shut off the boiler can be given more water to make up for it, by continuing the injection.

193. (T-69) Should a boiler be as full as practicable at starts?

That depends upon what is meant by "practicable." Only enough water should be kept to furnish the steam needed for the work to be done. Sometimes it is "practicable" to make enough steam with half a gauge of water, at other times more water may be necessary.

194. (T-70) Should a boiler always be kept as full of water as possible?

No; a half to three-fourths gauge is enough. It is good practice to let the water-level vary to suit the needs of the work the engine must do. It is not HOW MUCH water is in the boiler, but it is rather WHEN TO FEED water and how much to feed, because each pound of water uses just so much heat when being turned into steam, no matter whether it is one pound of a large or one pound of a small quantity of water.

195. (T-70) If the steam pressure lags while the engine is working, how can you remedy the matter most economically?

By using good judgment as to how much and when to feed water and allowing the water level to vary freely according to the work.

196. (T-70) In a case of necessity, which would you permit to vary (within safe and reasonable limits), the water-level or the steam pressure?

The water level.

197. (T-70) Can you save any coal by permitting the water-level to vary occasionally?

Yes. Because each pound of water must have a given amount of heat supplied to convert it into steam.

198. (T-70) Does it injure the boiler to do so?

No.

199. (T-70) Does it injure the boiler to permit the steam pressure to vary?

Yes.

200. (T-70) Why?

Because it causes the temperature of the metal of the boiler to vary and if fire is forced or injector improperly used contraction and expansion occurs with consequent damage.

201. (T-71) What are the proper limits of variation of the water-level?

Generally within two inches of the top and three inches of the bottom of the gauge glass. If a boiler is too full of water the space intended for steam is reduced, and consequently an unnecessary restriction of the amount of steam that could be formed is the result. Besides it causes water to be carried to the cylinders, because when the throttle is opened a large portion of the steam escapes, the pressure on the surface of the water is suddenly reduced and violent boiling takes place; and this throws spray into the steam.

202. (T-71) Do you understand that these Instructions and Rules for Boiler-Feeding are to be observed and enforced the same as the other Rules of the Management for the proper operation of the road?

NOTE:—The "Instructions and Rules" mentioned are those furnished for study by the railroad company. Upon them these questions and answers are based. The student should be able to answer truthfully that he does.

THIRD EXAMINATION

ECONOMICAL USE OF STEAM

LESSON XVIII.

203. (T-72) The coal consumption of locomotives depends mainly on—What?

The amount of steam used in doing the required work.

★204. (T-72) How many cubic feet of steam, of atmospheric pressure, can one pound of water produce?

27 cubic feet.

★205. (T-72) How many cubic feet of steam of 145 pounds pressure can one pound of water produce?

About 2¾ cubic feet. In other words, steam at 150 lbs. pressure is compressed into a space one-tenth that of steam at atmospheric pressure.

206. Considering the previous two questions and your answers—Is it plain to you why high pressure steam acts like a compressed spring in expanding?

The student should have thoroughly studied, and by observation and experience as well, ought to be able to answer that he does.

207. (T-72) What is meant by the term "full-stroke?"

When the steam pushes the piston without expanding. At full stroke steam of LOW PRESSURE is used, obtained by throttling, or otherwise. It leaves the cylinder at the same pressure at which it enters, because there is no expansion.

208. (T-72) What is meant by the term "cut-off" at 6 inches, or 8, 10 or 12 inches?

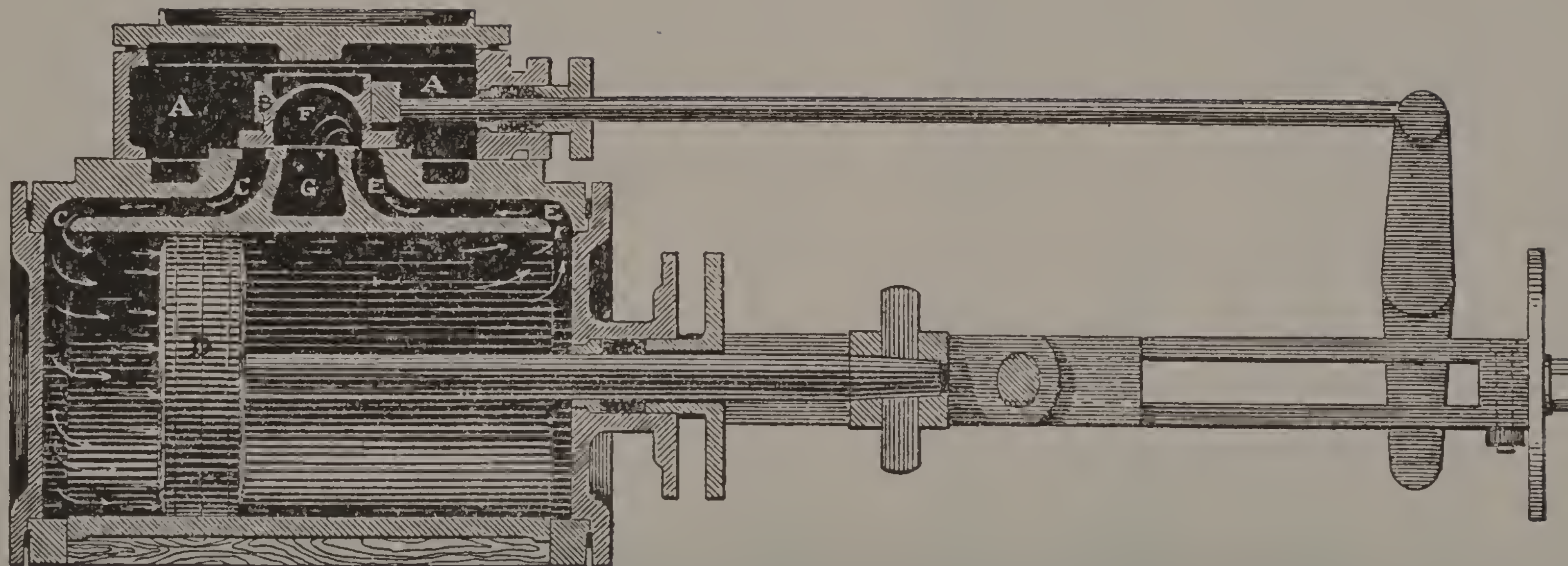


FIG. 12. SECTIONAL VIEW THROUGH STEAM-CHEST AND CYLINDER, ILLUSTRATING STEAM EXPANSION.

Shows the piston as having traveled *six inches*, or one-fourth a backward stroke. The valve has moved forward and *closed* the front steam-port, C C, CUTTING OFF the flow of steam to the cylinder. The steam so far admitted and imprisoned in the cylinder, pushes the piston the remainder of the stroke by its EXPANSION.

A six inch cut-off is a "short cut-off." The others are "late cut-offs." They allow the steam to expand in the cylinder after it is shut in.

209. (T-72) What is meant by the term "expansive use of steam?"

The expansive force exerted by the imprisoned steam as it rushes to get out pushing the piston as it expands just as a powerful compressed spring would when expanding. At a short cut-off steam of high pressure is admitted to the cylinder while the piston is moving over about the first quarter of the stroke—about six inches, at that moment steam from the boiler is shut off by the valve. The imprisoned steam instantly expands, the expansive force pushes the piston to the end of the stroke, increasing in volume four times but decreasing in pressure to only one-fourth what it was when cut-off.

210. (T-72) How can steam be used expansively in a locomotive's cylinder?

By admitting a certain amount to the cylinder and cutting off the admission of any more by the action of the valve.

★211. (T-72) If steam throttled to 77 pounds pressure is admitted into an 18-inch cylinder during the full stroke of the piston—How much steam will be used in that stroke?

Nearly six-tenths of a pound.

★212. (T-72) If steam of a 140 pounds pressure is admitted through a wide open throttle during 6-inches of the stroke of the piston in the same cylinder and then cut off—How much steam will be used in that stroke?

About three-tenths of a pound, or one-half LESS than at full stroke, yet the pressure on the piston, and the work done is the same in each case.

★213. (T-72) About what portion of the heat imparted to a pound of cold water to turn it into steam of 145 pounds pressure is converted into WORK in a locomotive's cylinders?

About a fortieth part. The remainder, or thirty-nine fortieths, is lost through the exhausts. That is WHY every possible effort should be used to get from the expansive force all the energy or work it can be made to do before letting the steam escape through the exhausts.

The best practice has been toward using higher pressures and greater expansion. That is WHY strongly built boilers carrying 200 lbs. pressure (and with closely-notched reverse-lever quadrants to give fine graduations of the cut-off) and compound cylinders are used. The expansive force of the steam is used twice in compounds, first in the high pressure cylinders and second in the low pressure cylinders, before being released through the exhaust.

214. (T-73) After a train is started and as speed increases—How should the cut-off of steam be regulated, and to what extent?

It should be cut off as "short" as possible consistent with the kind of work the engine is to do.

215. (T-73) To make an engine do its best work with the shortest practicable cut-off—What is necessary to do with the throttle?

When starting, work the engine full stroke, then throttle the steam to avoid slipping the driving wheels. When forcing the speed the throttle should be wide open, so steam may reach the cylinders at as near boiler pressure as possible, but it should be cut-off as early in the stroke as can consistently be done. It is bad practice and very wasteful to run with the reverse lever latched in the quadrant notches where the valves are caused to cut off at eight, ten, or twelve inches of the stroke, and by increasing or decreasing the pressure of the steam in the cylinders by the throttle. As much as varying conditions permit the practice should be avoided.

With the modern close notched reverse lever quadrants and balanced valves there should be no reason for this wasteful practice.

216. Is this your practice? If not, frankly state the reason.

(Students should answer according to their experience.)

217. At about what point of the stroke does your "working notch" cause a cut-off?

(Answer this question from your own experience.)

218. Are the three examples in this Lesson, showing the results of using steam in different ways, clear to you?

The student should be able to answer that "they are" if he has studied them properly and coupled same with his observations and experience.

THREE ILLUSTRATIVE EXAMPLES

FIRST EXAMPLE—SIX-INCH CUT-OFF

(From Railway Educational Association's Manual.)

"With an engine having cylinders 18 by 24 inches, and 145 pounds boiler pressure, we admit steam of 140 pounds pressure THROUGH A WIDE-OPEN THROTTLE to the cylinders until cut off at SIX inches of the stroke.

"We will watch the work of the steam in one cylinder, which will show what takes place in both.

"The smooth face of the piston presents a surface of 254½ SQUARE INCHES. Each inch the piston moves leaves a space behind it of 254½ CUBIC INCHES. In this way the volume and weight of steam in the cylinder at any point of the stroke may be measured, as the weight of any volume of steam of any given pressure is known.

"Our cut-off is SIX inches, and when the piston has moved six inches of the stroke we have admitted nearly nine-tenths of a cubic foot of steam, which at this pressure weighs three-tenths (.3129) of a pound.

"Steam is cut off from the cylinder by the valve at this point, the portion of it imprisoned in the cylinder acting like a compressed spring overcomes the resistance of the piston, and in forcing it to the end of the stroke expands to FOUR times its volume, and decreasing in pressure as it expands, is, at nearly the end of the stroke, exhausted at a pressure of 35 pounds.

"The average pressure upon the piston during the stroke was 77 pounds per square inch."

SECOND EXAMPLE—EIGHT-INCH CUT-OFF.

"With the same engine and cylinder and pressure in the boiler, we admit steam to EIGHT INCHES of the stroke before cutting it off; and as we only wish the engine to perform the same amount of work as in the first example, we must throttle the steam, and REDUCE ITS PRESSURE as it enters the cylinder to 117 pounds.

"This pressure will, when cut off at eight inches, cause 77 pounds average pressure on the piston during the stroke. In allowing the steam to follow the piston eight inches of its stroke we admit 1.18 cubic feet of steam, which at this pressure weighs a little over one-third (.347) of a pound. In this case, while doing the same work, we have used three-hundredths (.0342) of a pound of steam MORE than in the first example.

"The steam in this case expands to but THREE times its volume and escapes through the exhaust at 39 pounds pressure. We have measured the loss for one stroke of one piston; let us measure the loss for a complete revolution of the driving-wheels, during which each piston would make two strokes—four in all; so 4x.0342 equals .1364—over an eighth of a pound.

"If our driving-wheels are 63 inches in diameter they will revolve 320 times in running one mile. As we are wasting an eighth of a pound of steam per revolution, we will waste 320x.1364 equals 43.6 pounds of steam in running one mile under the conditions of this example."

THIRD EXAMPLE—TEN-INCH CUT-OFF

"We will in this case allow the steam to follow the piston TEN INCHES of the stroke before cutting it off, and we will throttle the steam still more than in the last example, so that the engine shall perform the same amount of work.

"The steam is throttled to 103 pounds pressure, which at this cut-off will cause an average pressure of 77 pounds. At this cut-off we admit 1.47 cubic feet of steam, which at this pressure weighs nearly half a pound (.403), five-hundredths (.056) of a pound more than in the last example, and nearly a tenth of a pound (.091) more than in the first example; yet the work done in each case has been the same.

"In this last example steam would expand but TWO AND A HALF times and would escape up the stack at 43 pounds pressure.

"An engine run in this way one mile would waste 116 pounds of steam as compared with the first example. Of course a pound of steam is a pound of

WATER turned into steam. As in locomotive practice we average about six pounds of water turned into steam per pound of coal burned, the 116 pounds of steam we are wasting per mile under the conditions of the last example, in DOING THE SAME WORK as in the first example, means a USELESS LOSS of 20 pounds of coal per mile, amounting to a loss of A FULL TON OF COAL in a trip of 100 miles."

★219. (T-73; First Example) What was the weight of the quantity of steam used during the stroke described in this example?

Three-tenths of a pound.

★220. (T-73, Second Example) What was the weight of the quantity of steam used during the stroke described in this example?

A little more than one-third of a pound.

★221. (T-73, Third Example) What was the weight of the quantity of steam used during the stroke described in this example?

Almost half a pound.

222. Do you understand that the WORK done in the cylinder during these three imaginary performances was exactly the same?

The student should have a thoroughly clear understanding so as to answer that he does.

★223. (T-73, Third Example) How many pounds of water are converted into steam by the heat from one pound of coal, in ordinary locomotive practice?

Six pounds.

224. According to the three examples described in this Lesson—What is the most economical way to use steam in the cylinders of any steam engine?

With a short or early cut-off, and a full throttle. Working the cut-off (hooking up or down) according to working requirements.

★225. Comparing the work done and steam used in the first and third examples—How many pounds

of STEAM are wasted per mile on an engine running under the conditions described in the third example?

116 pounds.

★ 226. How many pounds of COAL are wasted per mile in the same case?

Twenty pounds.

★ 227. How much does this amount to in a trip of 100 miles?

A full ton.

LESSON XIX.—USE OF STEAM—Continued.

228. (T-74) What is cylinder condensation?

Some of the steam condensing in the cylinder and becoming water.

229. (T-74) What causes cylinder condensation?

(Before answering study the following table):

TABLE COMPARING THE TEMPERATURE OF INITIAL AND EXHAUST STEAM, AND SHOWING THE CAUSE OF CYLINDER CONDENSATION

	Effective	Pressure.	Temperatures.	Difference of Temperature.
I.	Initial,	103 lbs.	339.9°	49.5°
	Exhaust,	43 "	290.4°	
II.	Initial,	117 "	348.3°	62.4°
	Exhaust,	39 "	285.9°	
III.	Initial,	140 "	361.0°	80.0°
	Exhaust,	35 "	281.0°	
IV.	Initial,	245 "	404.5°	192.0°
	Exhaust,	0 "	212.0°	

The metal of the cylinders take heat from the steam and conduct it away. It is a source of loss. Usually the condensation increases as the cut-off is shortened. It is present in all cylinders of engines running with an early cut-off. Cylinder condensation limits the economical use of the expansive force of steam. That is WHY compound cylinders are necessary.

★230. (T-74) What is the difference of temperature between steam of 140 pounds INITIAL pressure and 35 pounds EXHAUST pressure?

80 degrees.

★231. (T-74) What would be the difference between the temperature of steam admitted to the cylinder at 245 pounds pressure, and reduced during the stroke to atmospheric pressure?

192 degrees.

NOTE:—Refer to the third example in Lesson No. 18, and notice that steam was admitted to the cylinder at

103 pounds pressure and exhausted at 43 pounds pressure. Now consult Group No. 1 in the above table and notice that the temperature of the steam was 339.9 degrees when admitted to the cylinder at 103 pounds pressure,—and that when it was exhausted its temperature was 290.4 degrees,—a difference of nearly fifty degrees.

Remember, too, that the temperature of any pressure of steam is taken by the surface of whatever metal it comes in contact with, although it be in contact only a very short time, even as little as the fraction of a second. Therefore, the temperature would be changed very much if there were very wide differences of temperature between the steam and the surface of the metal with which it comes in contact. For example: if the metal were very cold and the steam very hot, the metal would be greatly heated, but the steam would be severely chilled, and that would cause some of the steam to CONDENSE to water. When the "initial pressure" and temperature of the steam admitted to a cylinder are very high and the exhaust pressure and temperature are very low it indicates that exactly this form of condensation has taken place. The "fall of temperature" from its initial to its exhaust degrees of heat has given to the walls of the cylinder the heat of its lowest or exhaust temperature. The cylinder head and about six inches of the cylinder walls at the exhaust end have been made about fifty degrees colder than at the other (or initial) end of the cylinder. Bad results would not follow were the steam always admitted and exhausted from the same ends of the cylinder, which of course is not done. Hence the chilled end of the cylinder is a moment later in contact with the initial pressure steam of a new stroke.

Referring again to the third example in Lesson No. 18 it will be seen the initial-pressure steam for the new stroke on entering the cylinder would come in contact with metal surfaces about fifty degrees colder than its own temperature.

In locomotive practice the steam used is always ready to condense into water directly heat is taken from it IN ANY WAY. Thus when new hot (initial-pressure) steam comes in contact with the colder cylinder-surface a portion is condensed to water, and there is what is called "Cylinder Condensation."

Look now at the second example, Lesson No. 18, and notice Group 2, in the table. The temperature of the initial steam is 348.3 degrees, the exhaust steam temperature is 285.9 degrees;—a difference of 62.4 degrees. Notice Group 3 in the same table; it shows the difference in temperature between the initial and exhaust pressures of the steam as described in the first example;—the difference being 80 degrees.

It should be clear that while in the second example more steam and heat were used for a certain amount of work than were needed in the first example; and more were used in the third example than in the second example, the loss because of cylinder condensation was greater in the first example than in the two others.

Group 4 in the table is intended to make this quite plain. Steam of 245 pounds pressure is supposed to be admitted to a cylinder. It is cut-off and made to expand until, at the end of the stroke its pressure is equal only to that of the atmosphere. Its initial temperature would be 404 degrees, its exhaust temperature 212 degrees;—or 192 degrees colder than it was when admitted to the cylinder. Now, at the start of a new stroke if steam of great heat rushes into contact with cylinder surfaces 192 degrees colder than its own heat, the result would be a great amount of cylinder condensation causing much waste.

Hence the value of compound cylinders, in which to use steam which expands to many times its initial VOLUME.

Nevertheless, in locomotive practice the only limit to the extent to which steam may properly be USED EXPANSIVELY is the NATURE AND AMOUNT OF THE WORK TO BE DONE. The advantages of using the expansive force of steam to the greatest possible extent are not alone the saving of heat in the quantity of steam used. There are other important advantages that MORE than offset all the evils of cylinder condensation, as will be explained.

Refer again to the three examples of using steam. Recall that with a six-inch cut-off the exhaust steam left the cylinder at 35 pounds pressure; with an eight-inch at 39 pounds; and with a ten-inch at 43 pounds; the pressure increased as the length of the cut-off was INCREASED.

Since the escaping exhausts are used, in locomotive practice, to create the forced draft through the fire, a FOUR-FOLD ADVANTAGE IS GAINED, by using steam of high initial pressure, with early cut-offs, because:

1st. There is less steam in the cylinders to be exhausted.

2nd. Being at a lower pressure it is exhausted more easily.

3rd. There is a more full escape of steam, therefore there is less steam to be reimprisoned in the cylinder to cause back pressure.

4th. Leaving the nozzle at a lower pressure, gives less force to the exhausts, thus creating a milder draft through the fire; resulting in fuel economy, because it allows time for the hot gases from the fire to pass through the tubes less hurriedly, hence they are in contact with the heating surface longer, therefore more heat is given to the water in the boiler, because more TIME is allowed for HEAT TO PASS THROUGH THE METAL.

232. (T-74) Why are "Compound" cylinders used in steam engines?

Because with two or more cylinders there is less danger of condensation and of great differences between temperature of the initial and exhaust steam in any one of the cylinders.

★233. (T-75) Name four advantages, exclusive of economy of steam, which result from using high-pressure steam with short cut-offs, as compared with throttled steam and late cut-offs.

(1) There is less steam in the cylinders to be exhausted. (2) Being at a lower pressure it is more easily exhausted. (3) The steam more fully escapes from cylinder so there is less to be reimprisoned and to cause back pressure. (4) As it escapes through the nozzle at a lower pressure there is less force of the exhausts and consequently a milder draft through the fire which materially aids combustion.

LESSON XX.—USE OF STEAM—Concluded. WHAT THE INDICATOR SHOWS.

An indicator consists of a steam cylinder A and a paper-drum B. Within the cylinder is a piston which the pressure of steam admitted beneath it pushes upward. This upward movement compresses a spiral spring within the cylinder. When the steam pressure underneath the pistol falls, this spring expands and pushes the piston downward again. Steam

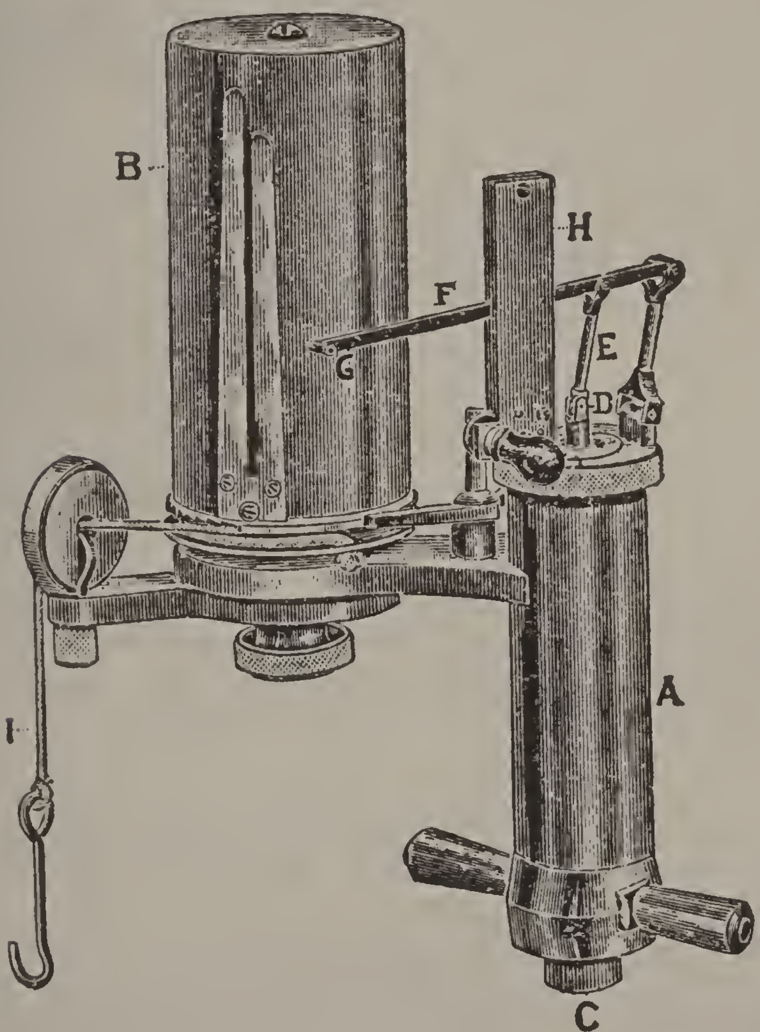


FIG. 13. A LOCOMOTIVE INDICATOR.

is conducted from the cylinder of the engine through a pipe of the engine to the indicator cylinder, where it is admitted at the bottom, C.

Through the steam pressure below and the expansion of the compressed spring above, the indicator piston is caused to move up and down, corresponding EXACTLY with the varying steam pressure in the CYLINDER OF THE ENGINE while working.

The purpose of an indicator is to RECORD the pressure variations exerted in the cylinder of an engine during certain strokes of its piston. This is done by means of the upright rod D attached to the top of the indicator piston through which it gets its upward and downward movements.

The movements of the piston-rod are made through the link E to the lever F, which at G holds a pencil. There is a curved slot inside the upright piece H in which a roller attached to the lever F moves. It is held so that a pencil draws a STRAIGHT LINE up and down, instead of a curved one.

The paper-drum B will revolve forward and backward. It is covered with a sheet of paper, or, as it is called, indicator card. When steam is admitted to the indicator cylinder, its piston RISES and pushes up the lever F, causing the pencil to draw a line on the card to INDICATE THE STEAM PRESSURE which is shown by the height it reaches.

When the drum is revolved before steam has been admitted to the indicator, the pencil which is resting at its lowest position, draws a STRAIGHT line around the card on the drum, near the bottom. This is called the "ATMOSPHERIC LINE" because no pressure but that of the ATMOSPHERE is then active in the instrument.

When the drum again revolves while steam of STEADY pressure is admitted to the indicator, the pencil RISES and draws a parallel line ABOVE the atmospheric line at a height to correspond with the

PRESSURE of the steam above the ATMOSPHERE. Should there be a rise or fall of steam pressure during the revolution of the drum the pencil moves correspondingly up or down, and INDICATES the variations on the card.

This records and shows what takes place in the cylinders of working locomotives and other steam engines.

The cord I which encircles the drum is attached to a lever which receives a "to and fro" motion from the engine cross-head. This cord can pull the drum around only one way, so a coiled spring is placed inside the drum to draw it back when the cord is relaxed. Thus the drum is made to revolve ONCE while the cross-head is making ONE stroke.

The tension of the spring exactly balances the steam pressure that compresses it. As the drum is revolved by the stroke of the cross-head, the pencil traces on the card an ACCURATE RECORD of what the steam does in the cylinder of the locomotive during any stroke of the piston.

Diagram (Fig. 14) is the record an indicator would make showing the action of steam in a locomotive cylinder during a stroke of its piston under supposedly perfect conditions. The piston is at the beginning of a stroke. The throttle is open, admitting steam of 150 pounds pressure to the cylinders of both engine and indicator. The pistons in each move. The indicator piston rises and makes the pencil draw the perpendicular "ADMISSION LINE" on the card from X to A to a height showing 150 pounds pressure.

As the cross-head moves on its stroke, the drum revolves, and the pencil draws the horizontal "STEAM LINE," A to B, during the first eight inches of the stroke. Steam is cut off at eight inches. Expanding it falls in pressure. The pencil draws the "EXPANSION CURVE," from B to C, until at seventeen inches of the stroke the exhaust port is opened. Now the pencil, suddenly falling

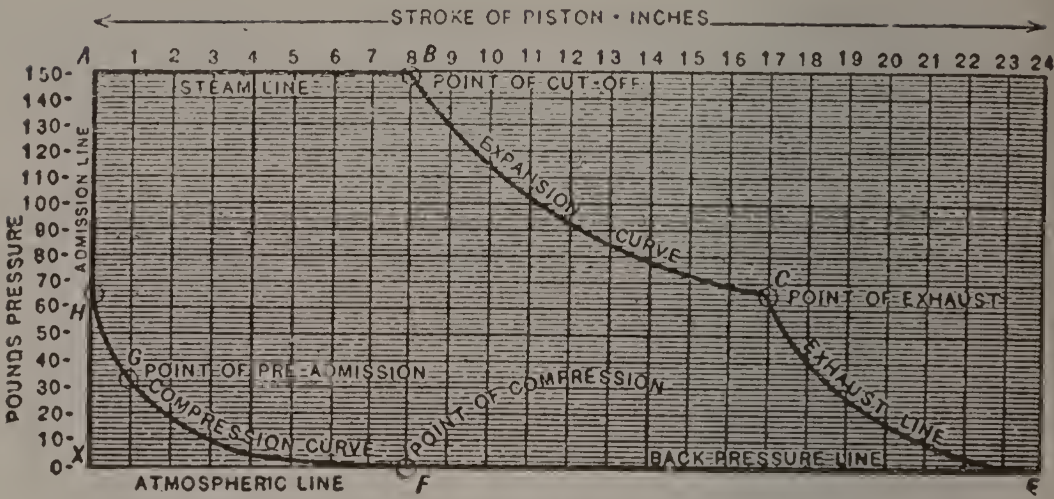


DIAGRAM FIG. 14. THEORETICALLY PERFECT.

with the pressure, draws the "EXHAUST LINE," C to E, to the end of the stroke, twenty-four inches.

When the return stroke begins all the steam of the stroke just finished has escaped from the cylinder, so the pencil falls to the atmospheric line. Returning as the drum is drawn back by the spring inside, it draws the "BACK PRESSURE LINE," E to F, above the atmospheric line. This indicates NO back pressure; but near the end of this stroke, the exhaust port is closed and the imprisoned AIR in the cylinder, compressed by the advancing piston, increases in pressure, and the pencil draws the "COMPRESSION CURVE," F to G. One inch before the piston reaches the end of this stroke, the valve opens the steam port and the pencil draws the "PRE-ADMISSION LINE," G to H.

ACTUAL PROOF OF THE ECONOMY OF SHORT CUT-OFFS IN PRACTICE.

The diagrams shown here, Nos. 15 and 16, were made by an indicator on a locomotive in passenger service. They illustrate the economy of short cut-offs.

DIAGRAM NO. 15—FULL THROTTLE.

In the case of diagram No. 15 the boiler pressure was 145 pounds. The throttle was WIDE OPEN admitting to the cylinders steam of 140 pounds pressure. The cut-off was at EIGHT INCHES of the stroke. The steam was exhausted at 38 pounds pressure, at 18 inches of the stroke. There was an average pressure of 70 pounds, 186 horse-power, at a speed of 28 miles per hour.

The cylinder was 19 by 24 inches. The smooth face of the piston presented a surface of 283.6 square inches. For each inch the piston moved, the space left behind was 283.6 cubic inches.

At the point of the stroke where the exhaust commenced there were 2.95 cubic feet of steam in the cylinder, of 38 pounds pressure, weighing over a third of a pound (.374), the weight of steam used in the stroke.

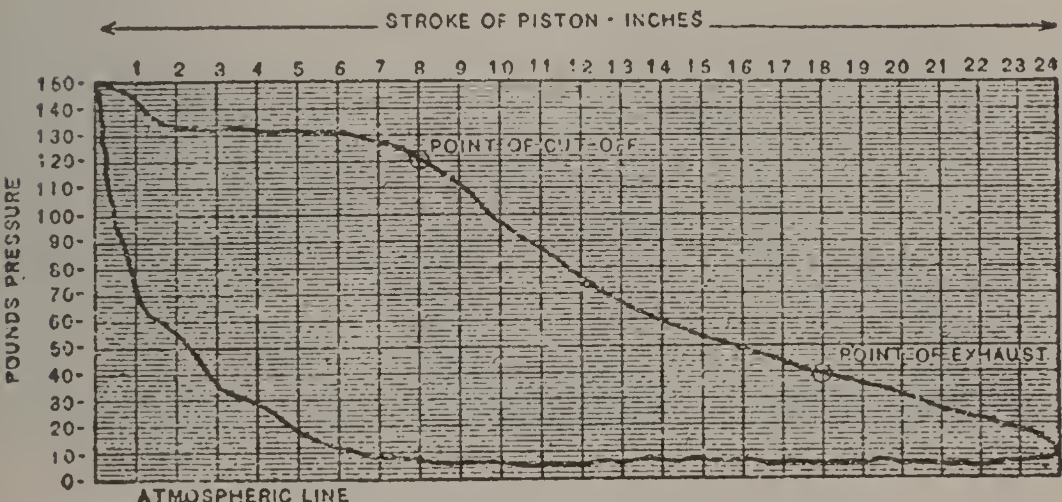


DIAGRAM FIG. 15. FULL THROTTLE.

Showing steam of 140 pounds pressure cut off at 8 inches of its stroke, the exhaust beginning within 6 inches of the end of stroke when the pressure was 38 pounds.

Four times this amount, or one-and-a-half (1.5) pounds of steam were used in one revolution of the driving-wheels. The driving-wheels were 63 inches in diameter. They revolved 320 times while running one mile. Hence 320x1.5 equals 480 pounds of steam per mile were used by the engine while running under the condition shown.

DIAGRAM (FIG. 16)—STEAM THROTTLED.

DIAGRAM No. 16 was made on the same locomotive under the same conditions. In this case the boiler pressure was the same, 145 pounds. The steam was throttled to 130 pounds and was allowed to follow the piston ELEVEN INCHES of the stroke before it was cut off.

At twenty inches of the stroke it was exhausted at a pressure of 53 pounds, so there was an average pressure of 75 pounds, 188 horse-power, at a speed of thirty miles per hour.

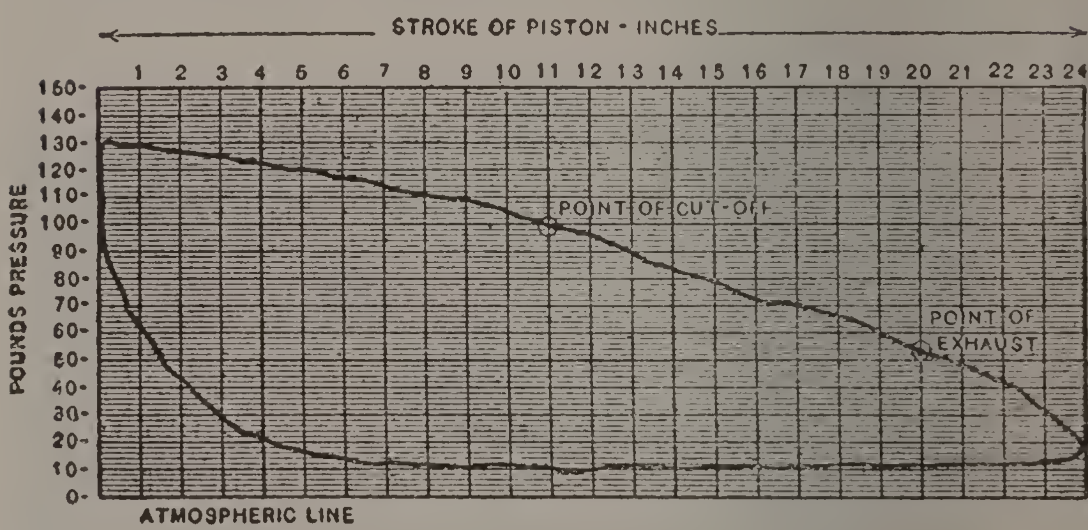


DIAGRAM FIG. 16. STEAM THROTTLED.

Showing steam of 130 pounds pressure cut off at 11 inches of the stroke, the exhaust beginning within 4 inches of the end of the stroke when the pressure was 53 pounds.

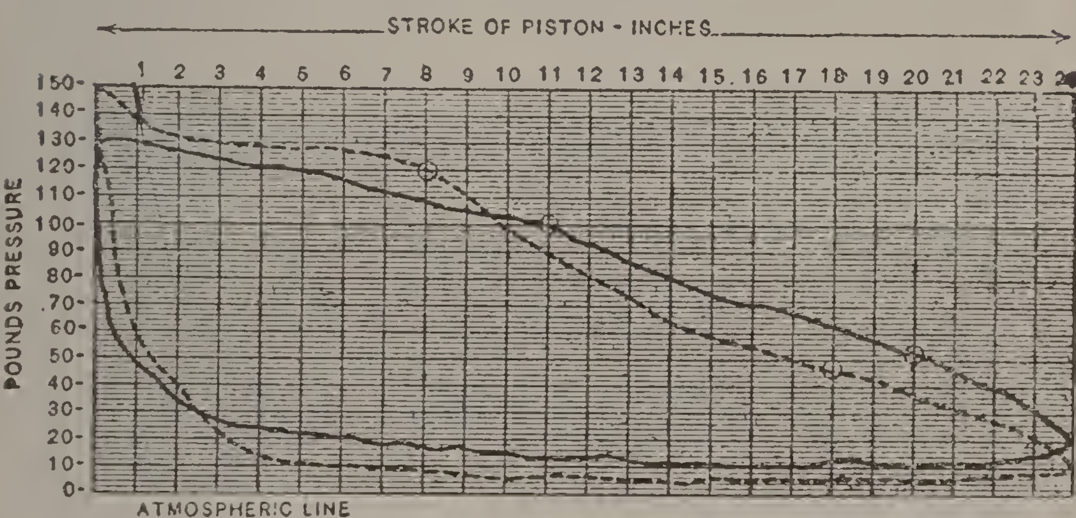
At the point of exhaust there were 3.28 cubic feet of steam in the cylinder, which at 53 pounds pressure weighed .526 of a pound, the amount used in this stroke. At each revolution 4x.526 equals 2.1

pounds of steam were used, and 320x2.1 equals 672 pounds per mile.

It can be seen therefore that the work done by the later cut-off, as shown in diagram No. 16, was rather more than with the early cut-off, as diagram No. 15 shows, but it was done at an EXTRAVAGANT waste of steam and fuel, as may be seen by comparing the two.

By the early cut-off, 480 pounds of steam were used per mile run. By the late cut-off, 672 pounds of steam were used per mile run. A difference of 192 pounds of steam per mile. This difference took 32 pounds of coal to convert water that was used into steam of boiler-pressure.

Hence the excess of work was done at an expense of 32 pounds of coal per mile, AMOUNTING TO A TON AND A HALF IN A TRIP OF 100 MILES.



COMBINATION DIAGRAM FIG. 17.

Diagram Fig. 17 shows diagrams 15 and 16 together. Their differences may thus be easily compared. The dotted lines show diagram No. 15. The black lines show diagram No. 16. The top line in each diagram shows the STEAM PRESSURE in the cylinder during the stroke in which steam was used. The bottom line in each shows the BACK PRESSURE during the return stroke in which steam was EXHAUSTED. The nearer approach of the bottom, or "Back Pressure Line," in diagram No. 15 to the "Atmospheric Line" reveals about SIX POUNDS LESS BACK PRESSURE as a result of using the SHORT CUT-OFF than in diagram No. 16, where a late cut-off was used. The conclusion must be obvious to any thinking man.

★234. (T-77) Considering that six pounds of water are evaporated per pound of coal burned in usual locomotive practice—How much coal would an engine burn in running 3,000 miles under the conditions shown by diagram No. 15?

240,000 pounds—120 tons.

★235. (T-77) Measuring in the same way—How much coal would an engine burn in running 3,000 miles under the conditions shown in diagram No. 16?

336,000 pounds, 168 tons.

★236. (T-77) With coal costing $2.50 a ton, state how much MONEY would be wasted in running an engine one month, or 3,000 miles, under the same conditions shown in Diagram No. 16 as compared with the same in Diagram No. 15?

48 tons at $2.50—$120.00.

237. (T-78) When an engine is working with the shortest practicable cut-off—Is it desirable to pull or keep the throttle full open, if the desired speed can be maintained with it PARTLY or NEARLY closed?

It is not.

238. (T-78) What is the most economical way to use steam on a locomotive while running along ordinarily?

Run with wide open throttle and as short a cut-off as possible. Get away from stopping places easily so as not to work engine too hard. Make up lost time after speed is gained out on the road. Never throttle down the pressure in cylinders unless engine is working fast with shortest possible cut-off than is needed to do the work in the required time.

239. Do you understand that this whole subject of using steam with as great expansion as possible, and, therefore, with as high pressure and as short cut-offs as are practicable, in order to save steam and fuel, is a matter for the exercise of good, careful, considerate JUDGMENT by an engineer, guided by a correct knowledge of conditions and desirous of operating his engine most efficiently and economically?

The student should be able to answer that he does.

240. Is this your aim?

The student ought to be able to answer that it is.