MASSACHUSETTS
INSTITUTE of TECHNOLOGY.

Locomotive Engineering.

A THESIS

by

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BOSTON,

1876.

Certain Points
in the
Development and Practice
of
Modern American
Locomotive Engineering.

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List of Drawings.

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Plate **B**. Details of Locomotive — Cylinder, plan, longitudinal and cross section — Piston, Steam Chest, Bed Plate, Pump, Cross Head, Throttle, Check Valve, etc, Scale 1 1/2 in. to the foot.

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Plate **E**. Tender for the Hinkley Locomotive, Side Elevation, Plan and Rear View.

–Position of the subject and its relation to Mechanical Engineering.–

Historical Sketch. 'The Locomotive Engine', it has been said, 'may be selected as the grandest and most important development of modern civilization and human skill.' It forms a great and important part of Mechanical, or Dynamical Engineering. In it we deal with dynamical science, the science of motion and of power. In our study the subject falls apart into what ~~is~~ are called the theoretical and practical aspects. 'Practice provides the facts; theory, the inferences in regard to those facts.' Hence, although but few parts of so large a subject can be selected, we may first review the practical division and inform ourselves upon what *has* been accomplished, with ad-

Present Development of Railroads — Statistics of the cost and extent of English and American Railroads, and the number of Locomotives employed.

vantage before applying those theoretic principles by which to criticise what the former has done.

The existence of the locomotive engine is dependent upon the invention of railways. Of these there now exist over 67,000 miles in the United States, and in England over 15,540;* the former constructed by the expenditure of a capital of $3,150,000,000., and the latter, although of only 23 per cent the extent of ours, at a cost of $2,650,000,000. The aggregate locomotive steam power in the world, on the estimate of Dr. Engel, Director of the Prussian Statistical Bureau, from reliable railroad returns, is equivalent to 10,000,000 Horse Power., while he estimates the total of all other engines in use — land and marine — to be 4,400,000 Horse Power.

*At the end of 1872 and 1870 respectively —
"Scientific American."

Historical Sketch,— Discovery of the mechanical power of steam,— 200 B.C to 1615.

This work was done in the United States by 14,223 locomotives, in 1873; by 10,933 locomotives in Great Britain, estimated from the returns of 1872; and by those in fourteen other countries which he mentions, the total number approximating to 50,000. This shows the importance of the locomotive and railway interests in their present stage of developement.

It is recorded that the discovery that mechanical force is produced from the evaporation of water dates back two thousand years ago to Hero, of Alexandria. From his time to that of Cardan who described the Eolipile in 1571, no hint is detected that practical use was made of this knowledge.

The next stage in its develop ment, it is supposed, originated with the Marquis of Worcester in 1615, or the idea

The Marquis of Worcester, The First Useful Steam Engine. Five Epochs in the progress of Steam Power.

perhaps caught from Solomon de Caus on a visit to the cell where he was confined, in Paris. He proposed to use the power from the steam of boiling water for the propulsion of carriages upon the land and ships at sea* and invented the first practical steam engine —'an admirable and forcible way to drive up water by fire' which made it run 'like a constant fountain stream forty feet high.'

The history of the rise and progress of steam power, according to Mr. Bonine, may be divided into five epochs. The first, dating from Hero's time to the introduction of the first useful steam engine extends as we have seen above. Passing rapidly over the times of Galileo, who discovered that 'nature abhorred a vacuum to the extent of thirty-two feet of water'; and of Thomas Savery who, in

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*Brown's 'History of the First Locomotives in America.'

2d Epoch, Galileo's Discovery of the Vacuum and its Application to Steam Engines in 1698. 3d The Use of the Cylinder, in 1710. 4th, The Discovery of the Effects of the Jet, 1712, Improved forms of Engines, Improvement of the Valve Gearing in 1718.

1698, first *produced* a vacuum which could be used to turn to account the elastic force of steam below the atmospheric pressure in addition to that above the atmospheric pressure previously employed, we find the second epoch to add the important discovery of a *vacuum* and its *application* to *steam engines*. The third epoch extends from the time of Denis Papin to Thomas Newcomen and John Cawley who first made, in 1710, a successful engine operating by a cylinder and piston, and is therefore marked by the Use of the Cylinder. The fourth epoch includes the accidental discovery by Newcomen and Cawley, in 1712, of the action of the jet or the *principle* of *injection*, Leupold's High Pressure engine, the improvement of the valve gearing by Beighton, in 1718, to the improvements by Smeaton in existing

The origin of Railways. Railroads with wooden rails originated in the North of England about 1630.

engines, in the year 1767. The fifth, extends from Smeaton's improvements and those of Watt, to the present time.

But in company with the progress in steam power, schemers were busily occupied in projecting inventions relating to rapid transit.

The essential accompanyment of the locomotive, the Railway, first came into existence. Historians pretend to trace in the hardened road surfaces of the early Egyptians, the Appian Way of the ancient Romans and the ruts in the streets of Pompeii, the precursors of our modern railroads. The actual roads, which were for a long time made with wooden rails, originated in the coal districts of the North of England about 1630. The rails were rounded upon the top so as to fit

Wheels, cast iron. First iron rails introduced in 1738. Flanged wheels introduced in 1789. The necessity for the locomotive. First attempts.— Sailing Coach.

the pulley-like cast iron wheels of the wagons. The first *iron* rails, or "plate ways", were laid in 1738. They had an upturned inner edge, or flange, and the wheels were flat. The change to putting the flanges upon the wheels instead of upon the rails was not made till 1789.

The necessities of the times developed the railroad and "paved the way" to the success of the locomotive. The people of that time, like the tendency of those of our time in reference to our metropolitan street railways, were dissatisfied with the slow, uncertain, expensive use of the horse as a motive power. The first attempt at an improvement was a 'sailing coach' and it deserves nothing further than mention. It has been stated that Sir Isaac Newton was the first to throw out the idea of the use of steam for land locomotion. In 1680, he ex-

The first idea of a locomotive! 1680. Sir Isaac Newton. Dr Erasmus Darwin's idea of a "Fiery Chariot."

plained, an Aeolipile like the earliest of known steam engines Hero's, placed upon wheels and moving by the reaction simply of steam flowing into the atmosphere. Perhaps the most curious and interesting genius connected with the subject was Dr. Erasmus Darwin, an Englishman who had the idea of a "fiery chariot" on which he corresponded with Benjamin Franklin. The idea occurred to him, it is said, "while riding about among his patients in his sulky, surrounded by scraps of paper on which he wrote poems, a pile of books, a hamper of fruit with cream and sugar," not to mention "a bag of oats, a bundle of hay and a pail for watering the horses." In 1765, he wrote to Boulton, as follows;—

*"As I was riding home yesterday I considered the scheme of the fiery chariot, and the longer I contemplated this favorite idea the more practicable it appeared to me. +++ "These things are required: 1st, a rotary motion; 2d, easily altering its direction to any other direction; 3d, to be accelerated, retarded, destroyed, revived instantly and easily; 4th, the bulk, the weight and expense of the machine to be as small as possible in

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*From Smiles' "George and Robert Stephenson" — Soho M.S.S.

The idea of a steam tractive engine, in 1759. A Model first constructed by James Watt in 1784.

proportion to its use: 'Let there be two cylinders, suppose one piston up, and the vacuum made under it by the jet d'eau froid. That piston cannot yet descend because the cock is not yet opened which, admits the steam into its antagonistic cylinder. Hence the two pistons are in equilibrio, being either of them pressed by the atmosphere. Then I say, if the cock which admits the steam into the antagonistic cylinder be opened gradually and not with a jerk, that the first mentioned piston in the cylinder will descend gradually and not less forcibly. Hence, by the management of the steam cocks, the motion may be accelerated, retarded, destroyed, revived instantly and easily. And if this answers in practice, as it does in theory, the machine cannot fail of success! Eureka!'

In 1759, the idea of a steam tractive engine was suggested by John Robison to James Watt, who, in 1784, made a model, his name being thus connected not only with the most important improvements in Stationary Engines, but also honorably recorded in the long list of eminent mechanical engineers who have worked upon the subject of the locomotive. But the first actual running locomotive machine, it is said, was made by Joseph Cugnot, a Frenchman from Lorraine, who, in 1769 made a three-wheeled affair with two single-acting cylinders whose pistons acted upon a wheel in front. Its power was not to be doubted, for, on its first starting it ran into a stone wall and threw it down. But, it made out to carry but four persons and its maximum speed was two and one fourth miles per hour. The appearance of the engine is shown in the figure.

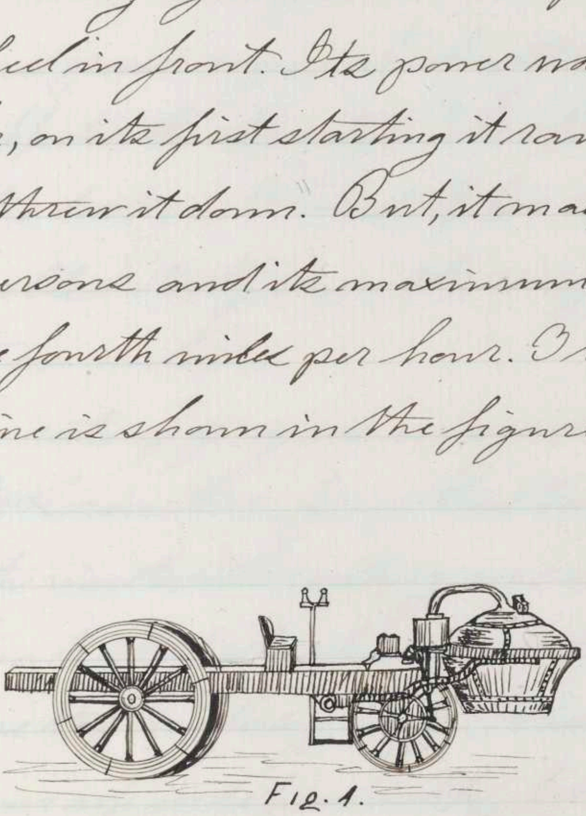

Fig. 1.

Cugnot's Engine.

The next person to be heard from was William Murdock, an employee of Boulton at the Soho Iron Works. He made a model, in 1781, which bears as much resemblance to our locomotives, as the 'Iron Horse' does to its

Oliver Evans, 1801. The First Railway Steam Locomotive run on a Tramway, Richard Trevithick, in 1804.

namesake in the animal kingdom. William Symington also made a working model. In 1801, Oliver Evans in our country constructed his "amphibious affair". In shape it was rectangular and its appearance decidedly clumsy. In the rear was a paddle wheel and inside a five horse power engine which acted on the wheels which supported the apparatus. The structure made its way to the docks in Philadelphia and, being launched, propelled itself down the river for a distance of sixteen miles.

The rate of progress in regard to Railways and the Locomotive, from this time, the beginning of the nineteenth century, was now all out of proportion to that which preceded. Previous to this time the Railway and Steam Locomotion had grown up independently, but Richard Trevithick, in 1804, is entitled to the honor of building the first railway locomotive ever constructed and tried upon a tram-road. "The cylinder of this engine was 4 3/4" in diameter and was placed horizontally in the end of a cylindrical wrought iron boiler."* The waste

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* Smiles.

Description and Performance. Blenkinsop's Spur-gear Locomotive, 1811.

steam entered the stack. The boiler carried 40 lbs. steam pressure. The engine ran upon four wheels. The performance of this engine was as follows;— "At the first trial it drew 10 tons of bar iron besides its water, fuel, and necessary carriages, for a distance of nine miles, at the rate of five and a half miles per hour."

The elementary difficulties, so to speak, in the employment of the locomotive now seemed to be over. Imaginary objections, as, the supposed want of adhesive power, being in a great degree overcome, it remained to perfect the mechanism, work up its details, and this has been continuously done up to the present time. There have been since then but few vital principles discovered. The next to construct a locomotive was Mr. Blenkinsop, in 1811. The engine had two vertical cylinders, 8 inches in diameter and a cylindrical single flue boiler was employed. The four wheels upon which it was supported rested directly upon the rails, and were entirely unconnected with the motive mechanism. The machine was moved by cranks connected with the crossheads and pistons and acting through

Blackett's locomotive. George Stephenson. Performance of the Killingworth Engine. Relative economy of locomotives at par with Horse Power.

spur gears upon projecting pins which formed a rack upon the side of the rails. Here again is noted an improvement upon the clumsy gears and fly-wheel of Trevithicks engine. In the next, Mr Blacketts, we find that the rack rail had been dispensed with.

The wants of the times were now increasing, and previous machines were found practically to be inadequate, when George Stephenson took hold of the subject. It has been said "that George Stephenson was to the locomotive what James Watt had been to the Stationary Steam Engine," and the sequel confirms it. His first locomotive, the "Killingsworth engine", was constructed in 1814 and was on much the same plan is the type that preceded. On an up grade of 1 in 450, the engine drew eight loaded carriages of thirty tons weight at about four miles per hour. At this time, in point of economy, it is stated, that the locomotive, as compared with horse-power, was barely at par. The improvements that were now made by Stephenson consisted in the avoidance of the complexity arising from the use of gear wheels for which he

The Improvements of Stephenson — The Steam Blast — Experiments upon the Resistances to Locomotives.

substituted cranks upon the axles and the ball and socket joint between the cross-heads and connecting rods. The latter was necessary in order that the shocks given to the engine by the unevenness of the road might not damage the moving parts, for it is to be remembered that adequate steel springs could not then be made, and that the greatest difficulties in the way of perfecting the mechanism arose from the imperfect condition of machine tools and work. He introduced into the next engine that he constructed a very important improvement, the steam blast. Immediately, the power of the engine was doubled and what is equally important by its means coke and the hard coals could be used for combustibles. It would take too much space and be a digression besides, to notice here all the improvements that Stephenson made in railroads. He instituted experiments by which he determined the resistance to carriages upon railways. The three resistances to which he found his locomotives subject, were as follows;— 1° Upon the axles of the carriage; 2° the rolling resistance

Effect of Grades. The necessity for level Railroads. Origin of the ordinary gauge of Railroads 4'-8½" The Opposition to the introduction of Railways.

between the circumference of the wheel and the surface of the rail, and 3°, the resistance of gravity. Taking his resistance upon a level road at 10 pounds per ton of weight he found that a grade of one in a hundred diminished the useful power fifty per cent. The necessity of level railroads recognized by Stephenson was thus the next step in advance.

From this time, there seems to have passed some years of indifference to the working of the 'Puffing Billy', and the other early forms. The railroads were next improved, in idea at least, by the knowledge that malleable iron was superior for rails to the previous material which was cast iron. Our gauge of 4 feet, 8½ inches has also come down to us from the gauge of the wheels on the common vehicles of the road in the last century.

But it is necessary to pass over the absurd notions which preceded the opening of the next railroad. Like this from the 'Tyne Mercury'* whose editor sneeringly asked — 'What person would ever think of *paying anything* to be conveyed from Hexham to Newcastle in something

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* From Smiles.

The Principle developed in the 'Rocket,'— the Tubular Principle— extension of the Heating Surface. Performance of the Rocket.

like a coal-wagon, upon a dreary wagon-way, and to be dragged for the greater part of the distance by a *Roaring Steam Engine!*", the majority of them were equally weighty. At the opening, however, in 1825, the 'No. 1' engine *did* draw six wagons of coal, a covered coach for directors, twenty-one coal wagons full of passengers, and after these six more loaded coal wagons.

I suppose that it would hardly be considered orthodox, in this part of my subject to pass over mention of the 'Rocket', and indeed, the importance of the event it represents justifies the mention of this familiar and much worn affair. The improvement in the 'Rocket' consisted in the 'tubular principle' on which the boiler was constructed. The much needed heating surface was thus extended. For, the improvement of the locomotive boiler had and has always been far behind that of the engine details in perfection of construction and efficiency of working. In brief, the Rocket with 50 pounds of steam to the square inch, in the boiler, drew about 13 tons weight at an average speed of fifteen miles per hour, or at a maximum rate of twenty-nine miles per hour.

Introduction of the Locomotive in America in 1829. The First Railroad in the United States, 1827. American Projectors of the Locomotive, 1819.

The success of the Rocket on the 8th of October, 1829, brings us to the time of the introduction of the locomotive engine in America, and we shall henceforth leave the progress of the locomotive, and the railway system in England and other countries and confine ourselves more strictly within the limits of American Locomotive Engineering. The first railroad in the United States was of five feet gauge, and it extended from the Granite quarries of Quincy, Mass., to the Neponset river. It was completed in 1827, and antedates the actual running of the first locomotive by about two years. But as early as 1819 there were a few men, as Colonel Stevens of Hoboken and Benjamin Dearborn of Boston* who had turned their attention to the locomotive as railway motive power. The first locomotive run in this country, "the Stourbridge Lion", was of English make, and was run for the first time August 8th,—1829.* The gauge was 4'-3" and it failed of success on account of the weakness of the timber rails which formed the road. Simply mentioning the Peter Cooper experimental locomotive which was run in 1829,

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* Authority—Brown.

The First Locomotive of American make, 1830. American Railroad Construction. Speed reached by "The Best Friend."

the first locomotive built for a railway and of American make was the "Best Friend," in 1830. The history of railroad construction, like that of the Baltimore and Ohio Railroad which had at this time been started, forms a very interesting chapter in the literature of the subject. There were of course many differences in the influences which have developed our present railroad system, from those in England. Our country is upon a larger scale than the former, the rivers to be crossed, are deeper and wider, and the country hilly or undulating, which obliged the use of sharp curves which were necessary in order to avoid the great natural obstacles to the running of railroad lines here. It was on account of these short curves that the first accident happened to the "Best Friend." Under the lateral stress in passing a curve the wheels sprung so that they left the rails. On the wheels being strengthened and the engine repaired, this locomotive drew a "brigade" of four or five cars containing forty or fifty passengers at the rate of from sixteen to twenty-one miles per hour, and without the cars it reached a maximum speed of thirty-five miles.

Locomotive Establishments. Important Improvements during the last 45 years, — Iron Frames, Double Eccentrics, The Swivelling Truck, Six wheeled Engines & Coupled Wheels, 1842, Stephenson Link Motion, 1849. Steel Fire-boxes, 1861. Narrow Gauge Engines, 1870.

The 'Best Friend' exploded in 1831, from the carelessness of the negro who fired, who; we read, 'fastened the safety valve lever down and sat upon it' thus producing the first locomotive steam boiler explosion in America.

It would be pleasant to trace the improvements successively made in American Locomotives from this period through the forty-five years that have intervened, if time and space permitted. The history would be found to divide into the history of the present great Locomotive establishments, The Baldwin, Rhode Island, Hinkley, Grant, Danforth, Mason, Brooks, and Portland Companies Works.

Some of the important improvements that have been made since that time are iron instead of wooden frames, double instead of single eccentrics, the swivelling truck, the introduction of six wheeled engines and coupled wheels in 1842, and the adoption of the Stephenson link motion in 1849. In 1861, steel fire-boxes were used for the first time, and in 1870, our Narrow Gauge lines of three feet were projected from which much is expected in the future.

—The Production of Heat— Laws of Combustion.— The Sources of Heat — The Mechanical Sources.

Part I.

The Production of Heat, and the Laws of Combustion.

The Sources of Heat. There are three sources of heat in nature, *mechanical*, *physical* and *chemical*. As the immediate causes of heat the first of these sources may generate it either by friction, or by pressure. Friction is resisted motion. The consideration of the laws of the production of heat by friction relates to our subject only in the waste of power caused by it in running the machinery and its useful effect in the brake when it is employed in stopping the motion of the engine. Heat is in the next place generated by pressure, compression, or percussion. In producing it work or mechanical power is consumed in a certain definite ratio to the number of thermal units that it produces.

— The Physical Sources — The Chemical Sources — Chemical Attraction.

This is the converse of what is required in the locomotive, viz — the generation of power from heat.

The *physical* sources of heat, in the restricted sense of the word, physical, are Solar Radiation[*], Terrestrial heat, light, magnetism and electricity. The *Chemical* sources of heat are due to molecular action, motions and combinations. Of the nature of the force of Chemical affinity little is known. It is a powerful attractive force "exerted between molecules not of the same kind."[*] We have seen[†] that matter is endowed with a powerful attractive force called cohesion, or adhesion when acting between bodies of different compositions or of masses of matter of the same kind. Unlike this, the causes that operate to weaken cohesion, like heat and its expansive effect, often *induces* the action of chemical affinity, by their decomposing action. In short, we know only that certain elements of matter tend to unite when liberated *from the withholding* action of

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[*] Ganot's 'Physics'. [†] A part, 21 pages in length, entitled, On Force, Motion and Heat, and intended for Part I of this thesis, has been written, which discusses this, and which it has been thought best to omit.

other forces or conditions. The condition of substances, then, upon which this force tends to act, is, like a bent spring or a suspended body, that of *potential energy*.

Fuel, as we find it, is in this state. It needs only the liberation of the chemical force which acts between its constituent elements and an other elementary substance, to develope a great amount of power as heat. This combination of elementary substances accompanied by the production of heat is called *Combustion*. The chemical elements with which we deal in the rapid combustion necessary in order to generate steam are principally Carbon in the fuel and oxygen from the air. The former is said to burn, the latter to support combustion. In reality, both form the chemical union we call burning, and perform an equally active part. The fuel may be in either of the three states of matter; as the solid, Coal; the liquid, Oil; or the gas Carbonic acid, and it constitutes the expensive part in the generation of steam both from the labour necessary in obtaining it, and its carriage and handling. The oxygen of the air is only mechanically mixed with it, requires no force to separate it from the nitrogen, is always at hand and constitutes the inexpensive part of combustion in the locomotive engine.

Many attempts have been made to employ as fuel gases, liquids and even water assisted by oil which sustains the necessary temperature, but none have as yet been found to answer as well as those which can be used in the solid state. The natural solid combustibles are*

Anthracite Coal,
Bituminous Coal,
Lignite,
Peat. and
Wood.

The artificial are Coke and Charcoal. Of each of these there are numerous varieties differing, the former according to the coal basin where mined, the latter by the processes of their manufacture,

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* Trowbridge's "Heat and Heat Engines".

Anthracite and Bituminous Coal, and Wood the fuel for Locomotives in New England. Five important Points in the Theory of Combustion.

in their composition and value as heat producing substances. The artificial fuels are not used on locomotives in this country.

We may select the three following natural products as types of the fuel used on the New England roads.

Anthracite, — Lackawanna,
Semi-Bituminous, — Cumberland (Navy Yard),
Wood, — Dry Pine.

Let us apply the principles of combustion to at least one of these and determine by theory its value.

There are five important points in the theory of combustion.* First, in order to insure self-sustaining combustion it is necessary to raise the combustible to what is called the *temperature of ignition*. Second, a chemical change takes place, viz., the union of the elements of the fuel with the oxygen of the air. Third, an extraordinary developement of energy ensues. Fourth, the amount of this energy is *constant for the same* fuel and va-

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*Joseph P. Cooke Jr. "The New Chemistry."

—Table I; The Chemical Elements concerned in the Combustion of Coal.

ries as the amount of fuel burned. And fifth, the intensity, or temperature of the products of combustion depends upon the rate of combustion.

All chemical elements unite in definite proportions by weight, which ratios to hydrogen as a standard, are called their Chemical Equivalents or Atomic Weights. For the sake of distinctness we may write the four elements with which we have most to do in the following way;—*

TABLE I.

Name of Element.	Symbol.	Chem. Equiv. by Weight.	Chem. Equiv. by Volume.	Specific Heat, by Weight.
Nitrogen.	N	14	$\boxed{\text{N}}$	.2438
Oxygen	O	16	$\boxed{\text{O}}$	.2174
Hydrogen.	H	1	$\boxed{\text{H}}$	3.405
Carbon.	C	12	$\boxed{\text{C}}$	---------

When Coal is subjected to destructive distillation by a continued application of heat, volatile products will come off, composed of the two elements carbon and hydrogen.

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* From Wilson's "Treatise on Steam Boilers".

—The Compounds Formed—Calculations of the amount of Oxygen required per Pound of Carbon. Total Heat.

On coming in contact with the air, two important compounds, Carbonic Oxide, and Carbonic Acid, will be formed, with which we have now to deal. In the former case, a pound of carbon unites with an equivalent of oxygen; in the latter, it is known that double the weight of oxygen thus combines, and the carbon thus uniting is perfectly burned and produces its maximum amount of heat. To find the weight of oxygen that one pound of carbon would thus require we take from the table the atomic weights and place them in this proportion;

$$12 : 32 = 1 \text{ (pound of Carbon)} : x = \frac{32}{12} = 2\tfrac{2}{3} \text{ lbs.}$$

and in like manner a pound of carbon burned to

(Extract from Porter, "On Force, Motion and Heat.")

§ The ~~Thermal~~ Thermal Unit is equal to the quantity of heat necessary, to raise one pound of water at its freezing* temperature, 32° Fah., through one degree, Fahrenheit, in temperature. This unit is very important, and will be used in estimating the evaporative power of fuel.

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* It is usually taken at its point of maximum density, or 39.1° F, and this is given by Rankine; but for the present purpose it is more convenient to take it as given above, and the difference is practically inappreciable. The authority for so doing is Chas. T. Porter in his "Treatise on the Indicator. Constant atmospheric pressure is presumed.

– The Compounds Formed – Calculations of the amount of Oxygen required per Pound of Carbon. Total Heat.

On coming in contact with the air, two important compounds, Carbonic Oxide, and Carbonic Acid, will be formed, with which we have now to deal. In the former case, a pound of carbon unites with an equivalent of oxygen; in the latter, it is known that double the weight of oxygen thus combines, and the carbon thus uniting is perfectly burned and produces its maximum amount of heat. To find the weight of oxygen that one pound of carbon would thus require we take from the table the atomic weights and place them in this proportion,

$$12 : 32 = 1 \text{ (pound of Carbon)} : x = \frac{32}{12} = 2\,2/3 \text{ lbs.}$$

and in like manner, a pound of carbon burned to Carbonic *oxide* requires but 1 1/3 pounds of oxygen and forms 2 1/3 pounds of Carbonic Oxide.

The total heat, in British thermal units, which is sufficiently near to be taken as equal to that defined before§ . . . , (see footnote), that the one pound of carbon perfectly burned will produce is 14,500*, and when there is an insufficient supply of oxygen, so *that carbonic oxide* only is formed,

*Experiments by M. M. Favre and Silbermann.

—Weight of air required—

but 4,400 units of heat will result. To find the weight of *air* that would supply these requisite amounts of oxygen, we proceed as follows. Air is composed of *four* parts by weight of nitrogen to *one* of oxygen, or adding the chemical equivalents we have $4 \times 14 (N) + 16 (O) = 56 + 16 = 72 (N_4O)$.

Now the chemical equivalent of the resulting carbonic acid will be $12(C) + 2 \times 16 (O_2) = 12 + 32 = 44 (CO_2)$, and hence we have the proportion that the chemical equivalent of the oxygen in the air is to that of the nitrogen as the amount of oxygen burned per pound of carbon is to the amount of nitrogen left in the air supplied, or

$16(O) : 56 (N_4) = 2\frac{2}{3}$ (pounds of O_2) $: x = \frac{448}{48} = 9\frac{1}{3}$ lbs., and therefore the weight of air is $O + N = 2\frac{2}{3} + 9\frac{1}{3} = 12$ pounds, or in the case of carbonic *oxide*, one half, or 6 pounds.

To determine the amount of water that this one pound of pure carbon would evaporate from 212° Fah. we require to know the latent heat of steam, or the number of thermal units necessary to supply in ad-

– Evaporative Power of Carbonic Acid and Oxide from 212° and 62° Fah. –

er to evaporate a pound of water at 212° Fah. into steam at the mean atmospheric pressure. This is 965.7.* Hence the number of pounds of water required would be $\frac{14,500}{965.7} = \underline{15}$ pounds, and in the case of burning only to carbonic oxide, $\frac{4,400}{965.7} = \underline{4.55}$ pounds. In order to find the evaporative powers of these two gases from water at the ordinary summer temperature of 62° Fah., we must find the number of thermal units required per pound, by adding to the latent heat of steam, 965.7, the number of thermal units necessary in order to raise a pound from this temperature to 212°. This number is

$$965.7 + (212.900 - 62.011^{*}) = 965.7 + 150.889 = \underline{1116.589}.$$

The required evaporative powers are hence $\frac{14,500}{1116.589} = \underline{12.985}$, and $\frac{4,400.}{1116.589} = \underline{3.937}$ pounds, respectively.

As these theoretic results will prove useful in comparing with them the actual evaporative power of the fuel burned in locomotive fireboxes, we may collect them so

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*From Porter's Treatise.

— Table II. Results. Table III. Analysis of Coals and Wood. —

that they shall be exhibited at a glance by

TABLE II.

Name of Compound.	Symbol.	Chem. Equiv. by Weight.	Chem. Equivalent by Volume.	Spec. Heat by Weight. *
Carbonic Acid.	CO_2	44	$\boxed{C}+\boxed{O}\boxed{O}=\boxed{C}\boxed{O_2}$	.2163
Carbonic Oxide.	CO	28	$\boxed{C}\boxed{O_2}+\boxed{C}=\boxed{\begin{array}{c\|c}C&O\\ \hline C&O\end{array}}$	.2450
Air.	N_4O	72	$\boxed{\begin{array}{c\|c}N&N\\ \hline N&N\end{array}}+\boxed{O}=\boxed{\begin{array}{c\|c}N&N\\ \hline N&N\end{array}}\boxed{O}$	.2374
Water.	H_2O	18	$\boxed{H}\boxed{H}+\boxed{O}=\boxed{H_2}\boxed{O}$	1.0000

Name of Compound	Pounds of Oxygen requ'd per lb of Carbon.	Pounds of Air per lb of Carbon.	Total Heat. British Units.	Evaporative Power from 212° Fah.	Evap. Power from 62° Fah.
Carbonic Acid	$2\,^2/_3$	12	14,500	15.00	12.985
Carbonic Oxide	$1\,^1/_3$	6	4,400	4.556	3.937

The following table sufficiently explains the facts in regard to the three kinds of fuel that have been selected.

TABLE III.

Designation of Coal.	Weight per Cubic foot by Experiment.	Cubic feet of space required to stow a Ton.	Pounds of steam to one of Coal from 212°	Total waste in the state of ashes and Clinker from 100 pounds of Coal.	Weight of Clinker alone from 100 pounds of coal.	Steam from 212° from one pound of Combustible matter.
(Lackawanna.) Anthracite.	48.89	45.82	9.79	8.93	1.24	10.764
(Cumberland.) Semi-bituminous.	53.29	42.04	------	14.53	2.29	-------
(Dry Pine.) Wood.	21.01	106.02	4.69	0.30	-------	4.707

*Figures taken from Wilson's Treatise on Steam Boilers.

—The Physical Properties of Anthracite, Bituminous Coal and Wood.—

The table is taken from the report of Professor Walter B. Johnson to the United States Navy Department, and shows the relative weights, bulks, ash and evaporative powers of these three substances as obtained by experiment.

In its properties, the first, Anthracite, is hard, brittle and gives off very little gas in burning, its employment being thus free from the nuisance of smoke. It is difficult of ignition and requires skill in firing. The bituminous variety is what is called a "light caking coal"; requires a temperature of 1200° Fah. for its ignition, and gives off a large amount of gas which when imperfectly burned produces smoke. Wood also yields much gas. The advantages of fuel for locomotive use, are a maximum weight and therefore least bulk, maximum heating effect and hence the greatest proportion of combustible matter to the percent of ash, and cheapness. Bituminous coal has been found to answer best on the roads leading from Boston, although it costs $6.00 per ton. Although very smoky, as passengers attest, it has

—Calculation of the Total Heat of Combustion of Cumberland Coal.—

excluded the use of anthracite even after locomotives have been expressly fitted to burn the latter,* on the one hand, on account of its ease of management; and on the other hand, wood, on account of the great relative bulk of the latter.† The fuel used is a mere matter of what is the cheapest to perform the work required, and many things have to be taken into account, besides those above, such as the wear and tear they produce in the firebox, the burning out of the grate bars and the cutting away of the crown sheet and tube ends, by the attrition of hard particles, as in Anthracite.

Let C, H and O denote, respectively, the percents of Carbon, Hydrogen and Oxygen in one pound of fuel which we will take for the Cumberland coal at $C = 70.85$, $H = 6.$ and $O = 8.17$. Now, to calculate the total heat of combustion and thence the evaporative power of this fuel, we may apply Rankine's formula given below. The evaporative power from 212°;

$$E = \frac{14,500}{965.7} C' = 15 C' = 15 \left\{ C + 4.28 \left(H - \frac{O}{8} \right) \right\} \text{-----} (7)$$

† Wood is altogether used, I believe, in New Hampshire.

* Two locomotives on the Eastern R.R. had long fireboxes fitted to burn Anthracite but have gone back to burning soft coal.

— Equivalent Carbon. —

We first reduce the amounts of hydrogen and oxygen to an equivalent amount of carbon that would produce the same heating effect that these do. Now it has been found* that that part of the hydrogen and oxygen which unites in the proportion to form water has no effect on the total heat of combustion. Hence, since by weight this proportion is one part of hydrogen to <u>eight</u> of oxygen an amount, O, present, would unite with 1/8th the amount of hydrogen and therefore the excess of hydrogen which, in burning, furnishes heat, would be $(H - \frac{O}{8})$. Now one pound of hydrogen in burning produces 62,032 thermal units, while carbon produces but 14,500. Hence to reduce this amount of hydrogen to an equivalent of carbon we have the heating effect, $\frac{62,032}{14,500} = 4.28$ times as great as that of carbon, so that the equivalent of carbon in the fuel would be $C + 4.28(H - \frac{O}{8}) = 70.85 + 4.28(6 + \frac{8.17}{8}) =$ $70.85 + 4.28 \times 4.978 = 92.16$ percent $= C'$. The total number of <u>thermal units that one</u> pound of this

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* Experiments by Dulong — Rankine. Also Walter B. Johnson's Report to the Navy Department on American Coals.

—The Evaporative Power from 212° and 62° Fah.— Equivalent Foot-Pounds of Work.

coal can supply is therefore $H = 14,500\,C' = 14,500 \times .92.16 = \underline{13,363}$ its total heat of combustion. And hence the evaporative power from 212° Fah. is $E = \frac{14,500}{965.7} \times C' = 15 \times C' = \underline{13.82}$ pounds of water. Or, as before in the case of carbonic acid and oxide, the evaporative power from 62° F. would be the total heat, 13,363, divided by the number of thermal units necessary to evaporate one pound of water from 62°, or 1116.589.

$$\frac{13,363}{1116.589} = \underline{11.969} \text{ pounds of water.}$$

The total theoretic number of foot-pounds obtainable from each pound of this coal is found by multiplying the number of units of heat that it gives off by Joules equivalent, or

$$13,363 \times 772 = \underline{10,316,236} \text{ foot-pounds.}$$

The number of pounds of air required to burn this coal is practically the same as if the coal were pure carbon, in which case it has been found before to be 12 pounds. But here another consideration is necessary. In order to burn fuel, not only, 1°, the igniting temperature must be

—Weight of Air supplied for Dilution. Temperature of Fire.—

maintained, and, 2°, the theoretic amount of air supplied to the fuel, but, 3°, the air must be intimately mixed with it so that chemical combination can take place. To insure this, an additional quantity of air is required, called the 'air of dilution' since it dilutes the gases from the fuel and allows the air to reach every part. Rankine states that this quantity should be, in locomotives where a blast is used, equal to one half that required for perfect combustion, or 6 pounds, so that the total weight of the air supplied per pound of coal should be $12 + 6 = 18$ lbs, or in volume, at 32° Fah. $12\frac{1}{2}$ cubic feet $\times 18 = \underline{225 \text{ cubic feet}}$.

To find the temperature of the fire in the fire-box of a locomotive, with this coal, let T be the temperature required; x, the elevation of temperature above that at which the fuel is supplied, which may be taken at 62° Fah, so that $T = x° + 62°$ F. To find the amount of oxygen that the 92.16 per cent of carbon in one pound of fuel, would require we have

$1 \text{ (lb. of Carbon)} : 2.66 \text{ (lbs. of Oxygen)} = .92\% : x = \underline{2.447}$ lbs of Oxygen.

Now we have $.92 + 2.447 = 3.367$ pounds of Carbonic acid to raise through $X^{\circ s}$ of temperature, and in addition the nitrogen that is left from the 12 pounds of air, or $12 - 2.447 = 9.553$ lbs, and also 6 pounds of air supplied for dilution. To do this we have the carbon capable of giving a total heat of 13,363 thermal units, and therefore multiplying each of the former quantities by its specific heat, which we will take for Carbonic Acid and Air as given in Table II, page 29, and for Nitrogen at .2438,* we have the equation $3.367(CO_2) \times .2163 \times X^{\circ s} + 9.553(N) \times .2438 \times X^{\circ s} + 6\,(\text{air}) \times .2374 \times X^{\circ s} = 13,363$, since the temperature these quantities reach must result wholly from the 13,363 thermal units stored in the coal. Hence the intensity

$$X^{\circ} = \frac{13,363.}{.7282(CO_2) + 2.329(N) + 1.4244(\text{air})} = \frac{13,363}{4.4816} = 2982^{\circ}\text{ Fah.},$$

and $T = 2982^{\circ} + 62^{\circ} = 3044^{\circ}$ Fah.

We have now found just what the fuel that is burned in locomotive boilers is capable of doing, and the results may for convenience by grouped in the following table;—

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*These figures are Wilson's, Rankine gives .217, .245 & .238 and calculated from these the result comes 12° less or 2970°.

— Table IV Results. Rate of Combustion. —

TABLE IV.

Fuel.	Composition Carbon, %	Hydrogen, %	Oxygen, %	Volatile matter.	Earthy matter.
(Lackawanna) Anthracite.	87·74	-------	-------	3·91	6·35
(Cumberland.) Semi-Bituminous.	70·85	6·*	8·17	14·87	14·98
Wood, (Pine.)	-------	6·*	43·7	49·7	0·30

Fuel.	Reduced Equiv. of Carbon from 1lb of fuel.	TOTAL Heat, Therm. Units.	Evaporative Power from 212°F. lbs. of water.	Evaporative Power from 62° Fah. lbs. of water.	Foot-Pounds of Energy in one pound of fuel.	Temperature of Products in degrees Fah.
Anthra.						
Bitum.	92·16	13,363	13·82	11·97	10,316,236	3044°
Wood.						

Rate of Combustion. We have seen that the energy of the coal, the heat it developes and the mechanical work to which it is equivalent, is independent of the time. But, as will be seen further on, the time has a very great influence upon the Power of the locomotive engine, and this is traced back to what is called the "rate of combustion", or the number of pounds of fuel that can be burned on each square foot of grate, per hour.

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* Usual % as given by Trowbridge in "Heat and Heat Engines".

—Water and the Properties of Steam. Water, its Chemical Constitution.—

Part II.

On Water and the Properties of Steam.

In all heat engines there are two distinct operations, heat making and heat expending. In the former of these divisions the facts have been ascertained; the other, in which the atomic moving force of heat is to be transferred to the final substance, before it is directly changed into ~~the~~ mechanical energy of the engine, opens before us.

This substance is water, the most common and widely diffused of all natural substances except air. It may be considered in the following order, chemically, physically and dynamically.

Its treatment with respect to its chemical composition requires but little space, for but two facts are known with regard to it, its composition by volume and its composition by weight.* It is analyzed by decomposing it into its elementary gases, oxygen,

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* Eliot and Storer's Manual of Inorganic Chemistry.

–Water, Physically considered– its solvent power, States of existence.–

and hydrogen, and which can be easily done in a variety of ways, by sodium, passing its vapour over redhot iron and by electricity; and by synthesis, one volume of oxygen and two of hydrogen unite and condense into two volumes of water, or by reason of their relative atomic weights, its composition by weight is as one of hydrogen to eight of oxygen.

At the ordinary natural temperatures, water is a transparent and nearly colorless liquid. It has the property of dissolving and holding in solution, at certain temperatures, a number of chemical compounds, such as Carbonate of lime and of magnesia, sulphate of lime, carbonate of magnesia, chloride of sodium and magnesia and nitrate or chloride of calcium,* which produce a very great effect in corroding and incrusting the boiler plates of locomotives, and thus diminishing their efficiency. Like all other substances, it exists in three states determined by the quantities of heat it contains, and named as follows;–1° Solid,--- Ice.

2° Liquid,--- Water.

3rd Gas,--- Vapour or Steam.

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*"A Treat. on Steam Boilers". by Robert Wilson–Chap. Incrustation.

—Ice. Effects of a Continuous Supply of Heat,—

At the greatest degree of cold in nature, or about −45° Fah. we find the hard, brittle, crystallized solid called ice. Let one pound of this substance be taken, and its characteristics noted as they appear under a treatment of successive increments of heat. After raising its temperature to 32° F., which is done by the addition of 38.5 thermal units, since its specific heat is .5,[*] 142[†] units are necessary to melt the ice and convert it into a pound of water which has the *same* *sensible* *temperature* of *32°*. This is the first characteristic point. Instead of *expanding* by heat, it has contracted and its bulk is *less* than that of the ice by nearly 2½ cubic inches, at the same temperature and pressure. Continuing the heat, its density still increases, though more and more slowly, till we reach a temperature of 39.1° F. when we reach a second turning point in its characteristics peculiar to water alone. At this point of maximum density, one cubic inch of water weighs 252.69 grains, or its weight per cubic foot may be taken at *62.4 lbs*.[‡] the decimal places varying in value, as determined by *different commissions*, *from* *.379*[§] to *.454*[‖].

[*] Maxwell. [†] Acc. to Abbott's "Heat" and Rankine's St. Engine; Maxwell gives it as *144*. [‡] Rank. [§] Haswell. [‖] English Commission—Porter.

—Water, Dynamically Considered.—

At this temperature, the pound of water is taken as the basis of the unit of specific heat, its capacity for heat being also greater than that of any other substance known except hydrogen. At this temperature, its contraction ceases, and an expansion takes place, by every increment of heat, till, by the further addition of 173.9 thermal units, (212.9−39.0001=173.889*), the limiting point for the liquid state of water, or a temperature of 212° Fah., is reached. As before, the thermometer ceases to show an increase of temperature, on a continuation of the heat, the phenomenon of boiling takes place, ~~and~~ vaporization begins, and continues, till, by the further addition of 965.7 units, called the latent heat of steam, the pound of water becomes entirely evaporated.

The heat transmitted has therefore, apparently, two classes of effects, statical and dynamical, latent and sensible. The latter is apparent in its *external* work of expanding the substance, the former does the *internal* work of changing the state of the particles from the neutral condition

*Porter.

of neither attraction or repulsion, to the active and strongly negative property of repulsion. The effect of a further supply of heat to the gas that we now have, under atmospheric pressure, there being no fourth state that we are aware of, in which to enter, is to separate the water into its elements, and 17,000* more units will for this be required. Therefore, in applying heat to water, we consume units of *latent* heat, ~~which is not exhibited as sensible heat~~, as follows;— In changing

Ice to *water* at 32°F, *142* units, called the *Heat of liquefaction*,
Water into *steam* at 212°F, *965.7* " " "*Heat of Vaporization*,
Steam into its elements, *17,000* " " "*Heat of dissociation*.

Into the inquiry as to what is the *nature* of the heating of water we cannot here enter. In fact, a whole book† has been written upon the questions that arise in considering the heating, expansion, boiling, vaporization and evaporation of water, in which the author brings out many interesting points. The water, as it lies in steam boilers, is of varying *density, which increases* as the depth

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* Abbott's "Heat." † "On Heat and Steam" by Chas. Wye Williams.

– The Nature of the Heating of Water, Distinction between Vaporization and Evaporation. Ebullition –

below the surface of any horizontal layer, on account of the weight of the water above. The heating of water is almost entirely by convection, and this arises from the differences in *density* of the heated lower layers and the water above them. As the heated currents ascend, the colder ones descend by them, and the currents being in opposite directions, this transfer of heat takes place most efficiently.* Mr Williams maintains that particles of water are non-conductors and therefore non receivers of heat, but that in water, at all temperatures, a certain amount of *vapour* exists, which, expanding on a rise of temperature, causes that *apparent* expansion of water. *Vaporization*, or the *generating* of vapour from water, goes on at all temperatures. *Evaporation*, or the *separation* of the particles of vapour *from contact* with the water, takes place only at the free surface of the water. *Ebullition* occurs when the tension of the vapour in the water is sufficient to overcome the resistance due to the weight of the atmosphere.

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* This fact can be easily proved by theory.

– Steam. Definitions – A Fluid – A Perfect Gas – A Vapour. –

Steam is a fluid, generated by the vaporization of water, and approximating in its properties to those of a perfect gas.

"A Fluid is a body the contiguous parts of which act on one another with a pressure which is perpendicular to the surface which separates those parts";[*] and it is distinguished from substances in a different condition by the property which it has of not resisting a longitudinal tension when unsupported by a lateral force.

"A Perfect Gas is a substance in such a condition that the total pressure exerted by any number of portions of it, at a given temperature, against the sides of a vessel in which they are enclosed, is the sum of the pressures which each such portion would exert if enclosed in the vessel separately at the same temperature";[+] that is, its tendency to expand is independent of the existence of other substances in the same space.

[+]"A Vapour is any substance in the gaseous condition at the maximum of density consistent

[*] Maxwell. [+] Rankine, in "Steam Engine."

— The Physical Properties of Steam. — A complete Knowledge of its Properties rests upon its condition in three aspects, — its Density, Pressure and Temperature. —

with that condition. In the preceding important definitions which express the fundamental principles in all dealing with steam much shorter and better than I could in other language, certain *properties* of the states of the substances to which they relate have been selected by which to define them, and besides these steam exhibits a number equally important.

The mechanical or physical properties of steam may be stated as volume, pressure, density, temperature, both latent and sensible heat, invisibility, little conducting power, repulsion or expansibility, elasticity, compressibility and condensation.

But a complete knowledge of its properties rests upon three circumstances which determine its condition, its *density*, *pressure* and *temperature*. Between any two of these there is a fixed relation which is expressed by the following gaseous laws;—

Boyle's or *Mariotte's*; 'The volume of a portion of gas varies inversely as the pressure; or since the density is the reciprocal of the volume, the density varies directly as the pressure. Thus if V_0 and P_0 represent the volume and pressure of a perfect gas under one condition of, let us say, a temperature of 32° Fah., and V_1 and P_1 that under another temperature of, say 212° Fah., by this law we should have the proportion $V_0 : V_1 = P_1 : P_0$, and

$$V_0 P_0 = V_1 P_1 .$$

The second law of gases, Charles', Gay Lussac's, or Daltons, is, that "the volume of a gas under constant pressure expands when raised from the freezing to the boiling temperature, by the same fraction of itself, whatever be the nature of the gas".* Or, where $\underline{a}$ denotes the increment of volume between the temperatures t_0 and t_1 at which the volumes are respectively V_0, and V_1, as above, we have this equation true,

$$V_1 t_1 = (1 + \underline{a}) V_0 .$$

The expansion, $\underline{a}$, of any gas on raising its temperature from the freezing to the boiling

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*Maxwell.

— Determination of the Absolute Zero Point and what it signifies. —

point under constant atmospheric pressure, is ·3665°*, or $\frac{P_1V_1}{P_0V_0} = 1{\cdot}3665$. From this fact what is known as the 'absolute temperature', or the total amount of heat that a substance contains reckoning from what is called the 'Absolute Zero', is obtained. This point is found on the assumption that a gas will contract in bulk by lowering its temperature at the same rate at which its volume alters between the freezing and boiling temperatures of water. Or, as its decrease for 212 − 32 = 180°s is ·3665; for one degree it will be $\frac{\cdot 3665}{180}$ = .00203611 of its original volume, less, for one degree below the freezing point, or for the absolute zero point $\frac{1.000,000,00}{.00203611}$ = −491.13°, and −(491.13 − 32°) = −459°.13† below the zero of Fahrenheit's scale. At this point, theoretically, the gas would have no volume or pressure, V.P. = 0, and hence it has been called the point denoted by the 'disappearance of gaseous elasticity.' As a necessary consequence, the sub-

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*According to Maxwell,—Rankine uses ·365. †This is Maxwell's value, the Scientific American, Rankine. (See next page.)

— The Fundamental Property of Gases — Absolute Temperatures. How the subject of Steam must be considered. — Saturated and Dry or Superheated Steam. —

stance, on reaching this point, could contain no heat, and the "Absolute Temperature" or total heat in any substance is reckoned from this point and this is the reason why it is convenient to use it in calculations.

By combining the two gaseous laws we get the fundamental property of gases. Let us use Rankine's notation by calling T_0 and T_1 the absolute temperatures of freezing and boiling water, then

$$\frac{V_0P_0}{T_0}=\frac{V_1P_1}{T_1}=\frac{V_0P_0}{491.13}=\frac{V_1P_1}{491.13+180}=\frac{VP}{T},$$

and the fact is expressed that the product of the volume and pressure of any gas is proportional to the Absolute Temperature.

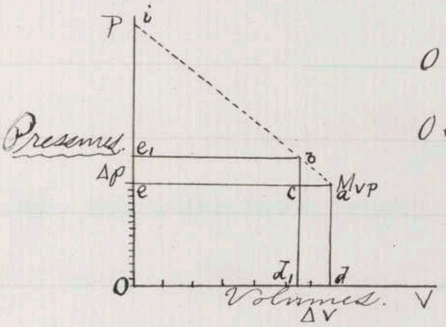
The generation of steam must be considered either under constant pressure or constant volume. When generated, its states of existence or conditions are two in number, either existing as Saturated steam, or as Dry, or Superheated steam. When and Porter give − 461.2° while Trowbridge gives − 459.4. The results in the calculations of this part though it is next to impossible to get them exactly, yet illustrate the principles and processes. These minute differences differ of course from slightly different coefficients used in obtaining them.

—The Generation of Steam under Constant Pressure and Constant Volume.—

formed in the water it is in the former state and forms visible globules, when it has evaporated from the water it forms vesicular vapour. When steam is generated and maintained in contact with water, under constant pressure, the volume of the saturated steam that results must increase. For, by the process, heat is added to the steam, its temperature increases, and hence, by what has been already seen, if the volume of the vessel in which it is generated is constant, as is the case in the steam boiler, successive portions of the steam as it is formed must escape from the vessel by the safety valve or otherwise, or the pressure would not be maintained constant. When the volume is constant, in the generation of steam, the effect of the increase of temperature is to produce pressure. The steam reacts upon itself, it presses upon adjacent particles and the sides of the vessel, crowds them into the diminished space allotted to each particle under these conditions, against the resistance caused by its tendency to assume its natural volume, and just as in all cases of compression the steam does the internal work of raising its own temperature and the total quantity of heat required to vaporize a given number of pounds of water, will be less than in the former case of constant pressure. Hence, for every pressure, a corresponding temperature necessary for evaporation will result, and thus we get for different pressures a series of values for the corresponding temperatures, and these constitute the boiling points of water under the pressure of its steam.

The immediate cause of the power of steam is its elasticity. If we go back of this we find that its elasticity is caused by its condition when the elastic property is observed, the condition of being under pressure, and this condition is, in turn, directly due to the units of heat it has absorbed.

The elasticity, or absolute pressure of steam, or any gas, may be well illustrated by this diagram taken from Maxwell. Let O be the origin of cöordinates, and M, a mass of any gas whose condition in respect to volume and pressure is represented by



$Od = ae = v$,

$Oe = ad = p$,

$ac = \Delta v$,

$bc = \Delta p$,

the position of the point a referred to the origin, and determined by the distances laid off on the rectangular axes OV and OP, on a suitable scale proportional to its actual volume and pressure. If now the pressure be increased by an amount Δp, ~~and~~ represented by the increase bc to the former ordinate, ~~bc~~, compression will take place and the volume will diminish by an amount Δv, and the new condition of the gas will be represented by the position of the point b. Since the original volume was represented by $Od = ae = v$, the cubical compression that the force Δp has produced is $\frac{ac}{ae} = \frac{\Delta v}{v}$. If now the line joining a and b be produced till it intersects the axis of pressures OP, the elasticity, E, supposing the rate of diminution of volume by every increment of pressure to be the same, will be represented by the distance ei, and from the relation between the sides of the triangles abc and aei,

—The Dynamic Effect & Motive Power of Steam.

—The Mechanical Equivalent of Heat.—

$ac : ae = bc : ei \therefore ei = ae \cdot \frac{bc}{ac}$, or $E = v \cdot \frac{\Delta p}{\Delta v}$, and the Elasticity of a fluid under given conditions is defined to be 'the ratio of any small increase of pressure to the cubical compression thereby produced.'

The Dynamical Effects, or the power of motion, of steam are the results of its repulsive tendency, its *elasticity* and *expansibility*, and it is by these properties that it is utilized. At the very foundation of the processes by which the power exerted by steam which has absorbed a certain quantity of heat, is utilized, is the number which has been determined as *The Mechanical Equivalent of Heat*. The equivalent number of foot-pounds to the thermal unit has been determined as the result of many hundreds of experiments and calculations, by Mayer, Joule, Sir W. Thompson, Rankine, Helmholtz, Hirn, Clausius and Regnault, and in many different ways. A method used by Hirn was on the principle of the rise in temperature produced in a block of lead when compressed by a blow from a swinging hammer falling through a certain height.

—Hirn's and Joule's methods of determination—
—Mayer's Calculation.—

One of the best of Joule's methods was that in which paddles were turned in water by means of weights falling through a certain height. The weights, and height through which they fell, gave the gross work done, and the friction of the paddles against the water produced a corresponding rise of temperature.*

A very neat determination is that known as Mayer's Calculation. The method is taken from Tyndall's "Heat Considered as a Mode of Motion", and is as follows;— Suppose a vessel one square foot in area, and containing one cubic foot of air at 32° Fah., to be heated till its volume is doubled. The coefficient of expansion of a gas, is, as has been seen, $\frac{1}{491.13}$ for each degree of temperature, so that it would require to be heated through 491.13 Fah. to double its volume, under constant pressure. The capacity of the air for heat, or its specific heat under constant pressure is .2377† times that of water, and the weight of a cubic foot .0807265† of a pound. Hence the quantity of heat expended, in thermal units, would be .2377 × .0807265 = .019189 lbs. of water heated 491.13°;

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*These two methods are fully given in Ganot's "Physics".

† Porter.

and the equivalent weight of water heated one degree would be .01918 9 × 491°.13 = 9.426 lbs. nearly. The result of the application of this heat is to expand the air against the resistance due to the pressure of the atmosphere, or what is the same thing, to lift a weight of 14.7 lbs × 144" = 2116.8 lbs. one foot high.

If now the volume had been kept constant, the specific heat would be less, as has been seen, or but .1683*, and the water equivalent found in like manner would be but .0807265 × .1683 × 491.13 = 6.686 lbs. nearly, for in this case there is no external work performed. Therefore the quantity of heat that would raise 9.426 − 6.686 = 2.74 lbs. of water through 1° Fah. has performed a work of 2116.8 foot-pounds, and the mechanical equivalent of the thermal unit is

$$\frac{2116.8}{2.74} = \underline{772} \text{ ft-pounds.}$$

This number has been reached after the comparison of a great number of experiments, and though it has been and is constantly used in calculations upon heat and power, its accuracy is even now doubted.

*Porter.

— The Condition of One Pound of Saturated Steam at the Atmospheric Pressure, in regard to Volume & Temperature. —

The condition of the one pound of saturated steam which has been traced, in its process of formation from the original pound of water with which we started, is as follows; — Its absolute pressure or elastic force is 14.7 (more exactly 14.696) pounds on the square inch, that is, it balances the atmospheric pressure. Its relative volume is 1644* times that of the water, it exhibits a sensible temperature of 211.986° F, contains 212.886 thermal units that are in the water before evaporation, and 965.709 thermal units absorbed in evaporating it, so that the total heat that the steam contains is

212.886 (sensible) + 965.709 (latent) = 1178.595 total.

If now the steam is generated under pressure, these values are greatly changed. If the pound of water is under a pressure produced by previously evaporated portions, in a confined space, and amounting to 120 lbs. to the square inch, Gauge pressure, above the atmosphere, as is usual in locomotives, the absolute pressure will be 134.7 lbs, the water will have to be heated to

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* Porter.

—Table of the Properties of One Pound of Saturated Steam under 140 lbs., 120 lbs., and Atmospheric Pressure.—

$349.78^{\circ 2}$ F. before ebullition begins, the steam will contain 353.877 thermal units of sensible, and 866.748 of latent heat, or a total of 1220.625, and its relative volume will be but 205.8 that of the water. In like manner, at 140 lbs., its condition will be very different from that at either of the other pressures, so that the properties of steam, at these three pressures, may be shown as follows;—

The Properties of One Pound of Saturated Steam.*

Gauge Pressure. Barom. 29.922" lbs per sq. in.	Absolute Pressure or Elastic Force. lbs per sq."	Temperature of Steam & Water or Boiling Pts. in Degrees Fah.	British Thermal Units, in 1 lb. from zero Fahrenheit.			Relative Volume, an equal Weight of water being 1.	Weight of one Cubic Foot. Pounds.
			Number in the Water.	Latent Heat of Vaporization or Number required for Evaporation.	Total Number contained in the Steam.		
0	14.7	211.986	212.866	965.709	1178.595	1644.0	.03795
120	134.7	349.782	353.877	866.748	1220.625	205.8	.30346
140	154.7	360.595	365.083	858.840	1223.923	182.6	.34250
1	2	3	4	5	6	7	8.

From this table, it is very apparent, in the sixth column, that, as the pressure and consequently the density of steam increase, as indicated in the last column, the total heat, or the sum of the latent <u>and sensible</u> heat, of steam

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*This table is found by interpolation from the figures given in Chas. T. Porter's book.

also increases. For rough purposes, however, it is stated by some writers that the total heat of steam is constant for all ordinary pressures, and approximates in value to 1200. The fact that this sum of the latent and sensible heat is not exactly constant was shown from experiments by M. Regnault, and C. E. Isherwood has deduced from his experiment the important facts that

With increase of Density,—Sensible Heat increases faster than the Latent Heat diminishes, &

With decrease of Density,—Latent Heat diminishes faster than the Sensible Heat increases,

and this latter statement, the converse of the former, is further criticised by Mr. Geo. B. Dixwell. As the temperature increases it has been found that the total heat increases for each degree of sensible heat, .305* of a degree, and this constitutes one of the differences in the properties of steam from those of a perfect gas which follows Mariotte's Law.

The utility of steam lies in its motive force. The motion that it will produce depends upon

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*Porter.

—The Utility of Steam lies in its Motive Force.—
—The inaccuracy in the Relative Volumes of Steam.—

the resistance to that motion and the heat that has been supplied, which furnishes all the power that the steam has, of doing work. In the generation of steam under the atmospheric pressure, that pressure, which is equivalent to a weight which would produce the same intensity of pressure, is the resistance, and the motion that it produces against this resistance, or the distance through which a piston of one square foot area would move on generating one pound of steam, to act upon it, is approximately found by multiplying its relative volume by the volume in cubic feet, of one pound of water; thus,—

$\left(\frac{1{,}000}{62.4 \text{ wht of a cu ft of water at } 32^\circ \text{F.}} = \right) .01602 \times 1644 = 26.33688$ cubic feet,

and this is all the work that can be got directly by the evaporation of one pound of water. At a pressure of 120 lbs. above the atmosphere, using the table, the volume produced would be $.01602 \times 205.8 = 3.29692$ cubic feet. To show the inaccuracy of these results, although they are used by Mr. Porter and are supposed to be the best attainable at present, it may be mentioned, first, that the relative volumes have never been

– Ignorance of the Rate of Expansion of Water at Temperatures above 212° F.

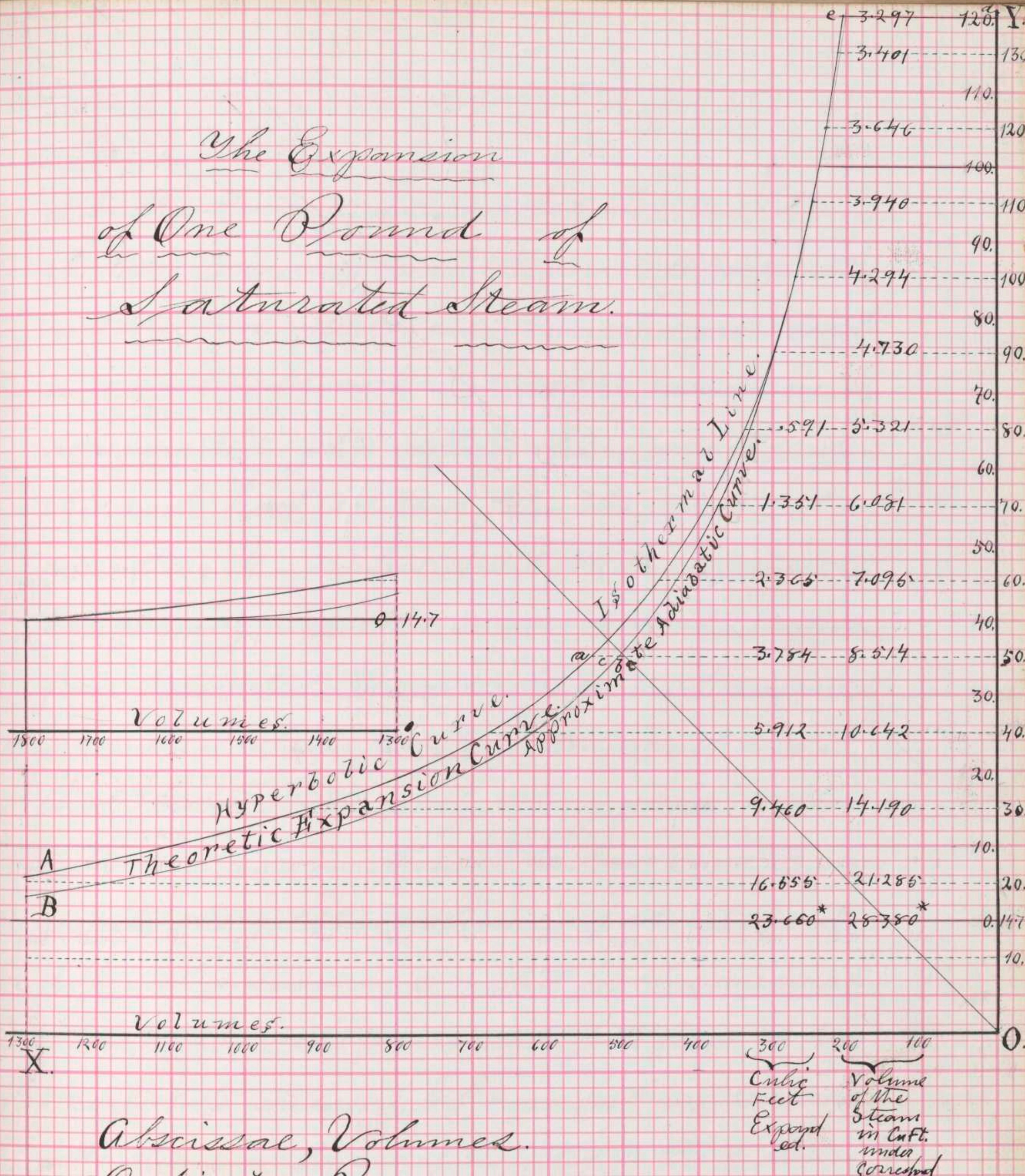
determined beyond dispute; and second, that it is grossly inaccurate to consider the volume of a pound of water as .01602 c. ft. at all pressures, and their corresponding temperatures. The expansion of water between its point of maximum density and the boiling point under atmospheric pressure, is .04332, as given by Porter, after correcting the volumes given by Kopp. And above this point its expansion is not known. The only facts we have by which to guide us, are its varying rates of expansion between the two temperatures given, and the fact that these rates increase with the temperature. The first differences of these rates increase, and the second diminish, so that it is seen that to find the probable expansion of water when under this pressure, and having a temperature of 349.78°, or 137.79 above the boiling point at atmospheric pressure, is an exceedingly complex matter, and it being necessary to go through these complex calculations for each pressure or temperature, separately, may explain why it has not been done. In using these uncorrected results, it seems

The Expansion of Steam—How it must be considered—as following an Adiabatic or Isothermal Curve.—

to me that we are sure of but one fact, that the volume obtained, or distance moved through by a piston of one square foot area, is *less* than the reality, roughly estimated, by ten or twelve hundredths.

To utilize any further steam in this condition, under the volume corresponding to its pressure, *Expansion* is necessary. This is, essentially, the enlargement of volume of the receptacle, such as the cylinder, in which a portion of steam is confined, and of course a result attended by it is a corresponding lowering of *pressure*. In considering the expansion of steam, we regard it as either following an *adiabatic* curve, which would be the case if there was a jacket of non-conducting material about the cylinder of the locomotive engine, and to the conditions of which it would approximate as the jacketing is better; and, second, it may be considered as following an *isothermal* curve when the cylinder is steam jacketed and sufficient heat supplied to the steam by the jacket to prevent condensation, or to maintain an equal temperature at all times in the cylinder. ~~In the latter case saturated steam should be used, in the former superheated~~. To exhibit the process of the expansion of steam, I have plotted the following curves taking as a basis the curves and figures given in Mr. Porter's book which are the most recent values given. ~~and probably the most accurate to be had~~. The expansion is shown for a Gauge pressure ~~of~~ of ~~to~~ 120 lbs. per square inch, as that is practically the highest pressure from which the steam would expand in locomotive cylinders, although the boiler pressure is often 20 lbs. greater. The curve A, represents the expansion of a perfect gas which, as we have seen, follows Mariotte's Law and is represented by the symbols $p \propto v^{-1}$, or the equation $pv = C$. (A constant.) It is, in its nature a rectangular hyperbola, of which the diagonal line is the axis, and the coördinate axes, the asymptotes. In the actual expansion of steam, when the volume increases, and the pressure diminishes, the heat contain-

The Expansion of One Pound of Saturated Steam.



Abscissae, Volumes.

Ordinates, Pressures.

" , left of axis, Gauge Pressures. (above the Atmosphere.)

" , right " " , Absolute " . (Elastic force.)

*At 15.2lbs pressure.

F.E. Galloupe.

— Effect of Condensation. —

ed in the steam is diminished also, as shown in the table previously given, the sensible temperature and total heat will be less. Now, whenever the volume increases work is done, for a resistance is overcome through a certain space, and to produce this work heat is taken from the steam, not only converting its surplus due to the lower pressure, but requiring more. Now, whenever heat is withdrawn from Saturated Steam under constant pressure, or at constant volume, Condensation must result. And this is continually taking place in the cylinders of locomotives. The lower curve, B, represents the relative volumes of the steam at different pressures corrected for this condensation. Thus, suppose the pressure to fall from 55 to 60 lbs. Absolute pressure. If a perfect gas, the volume of the steam would be represented by the distance of the point a from OX, but according to its actual relative volume, the distance would be less and the curve would pass through some point c, on the horizontal line. Now by condensation the volume is

– Equations to the Curve followed by the Expansion of Steam. Values of the Exponent in the Formula.

still further reduced by the amount cb, so that the position of a point b is determined. In like manner points were found for each five pounds fall of pressure, and the curve B drawn through them. Not a little confusion exists as to what is the actual curve followed by the expansion of the steam in the cylinders of engines. It is not the curve B, nor yet the hyperbolic curve whose equation is $pv = c$, $p \propto v^{-1}$, and it is not even positively known that it can be represented by the form $p \propto v^{n}$. Many attempts have been made to find out what value of this exponent most nearly represents the real curve. Rankine's approximate formulae give for the Adiabatic curve, $p \propto v^{-\frac{10}{9}}$, $n = -\frac{10}{9} = -1.1111$, and for the curve of a constant quantity of saturated vapour, $p \propto v^{-17/16}$, and $n = -17/16 = -1.0625$. Professor Channing Whitaker, in an interesting lecture* before the "Society of Arts" of the Institute, gave the results of Zenner's and Fairbairn and Tait's experiments, and those obtained by Mr. Head from actual measurements of indicator diagrams, and the values of n, given by Mr. Head, have nearly all a smaller instead of a larger

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*Mar 23d, 1876.

—The Efficiency of Steam. Carnot's Elementary Heat Engine.—

coefficient than those of Rankine's formulae given above, and that of Mariotte's curve. The conclusion of Prof. Whitaker, that the steam more nearly follows Mariotte's curve than any of the others, it seems safe to use, in the absence of more exact knowledge, for although theory points to a curve of a larger coefficient below it, yet in the majority of indicator diagrams, the expansion curve is above rather than below.

Finally, the Efficiency of Steam next requires attention. An important part of the efficiency of the locomotive engine, is that resulting from the use and the inherent nature of steam. In an elementary heat engine, represented by the diagram made by Carnot's engine, if the heat is received by the fluid at an absolute temperature T_1, and the fluid is thrown out of the engine at a temperature T_2, lower than T_1, and in which the fluid is successively expanded at the higher temperature T_1 on an isothermal curve, further expanded on an adiabatic; on the return stroke compressed under conditions that cause it to follow another isothermal curve for the cooler temperature T_2, and

– Absolute Efficiency. 2d Law of Thermodynamics. Intrinsic and Available Energy. Efficiency relative to the amount of heat supplied by the coal.

still further compressed on an adiabatic line, the efficiency of the fluid is the heat received by it on a single stroke minus the heat rejected with the fluid, H_2, divided by the total heat received per stroke, H_1, or

$$E = \frac{H_1 - H_2}{H_1} = \frac{T_1 - T_2}{T_1} = \frac{T_1 - T_2}{T_1 + 459^\circ.13}$$

and this is its absolute efficiency. The second *Law of Thermodynamics*, as stated by Maxwell, is 'that it is impossible by the unaided action of natural processes to transform any part of the heat of a body into mechanical work, except by allowing heat to pass from that body into another at a lower temperature.' The intrinsic energy of steam is its capacity for doing work due to the *total amount of heat* it contains reckoning from the absolute zero. The available energy is only the fraction of its total heat between its absolute temperature and the temperature of the surrounding medium to which temperature only it can be worked. Hence the practical efficiency of steam is the ratio of the work it can do on the piston to the total heat supplied to it, or $E = \frac{W}{H}$.

— The Resistance overcome and Work performed. —

Referring now to the curve which has been plotted and to the table at page 55, we find that steam generated at the atmospheric pressure has overcome the resistance of the atmosphere by the increase in its volume through a distance equal to 26.33688 − .01602 (volume of one pound of water) feet, and it has been shown that we may neglect the latter and that we will be on the safe side in so doing, for the volume is in reality <u>more</u> instead of <u>less</u> than 26.337 cubic feet. The resistance overcome is 14.7 × 144 = 2116.8 lbs. on the square foot and hence the work done is 26.337 × 2116.8 = <u>55,750</u> foot-pounds. To perform this work it was necessary to supply to the water at 212° F., 965.709 British thermal units of heat, equivalent to 965.709 × 772 = <u>746,527</u> ft-lbs. of work and which forms the latent heat of the steam at this pressure. Of this great amount, only $\frac{55,750}{772}$ = <u>72.215</u> thermal units have been utilized and the efficiency of the steam as far as the latent heat is concerned is $\frac{72.215}{965.709}$ = .074, or <u>seven and four-tenths per cent</u>.

But we have not even yet got the real efficiency as it is used in engines, relatively to the heat absorbed by it from that given out by the combustion of coal, for the total heat it contains reckoning from 0° Fah, is 1178.595 and if we assume the temperature of the water in the boiler to have been at first 62° F, the thermal units it contains being 62.011*, the actual number of thermal units supplied is 1178.595 − 62.011 = 1116.584 and the actual efficiency but $\frac{72.215}{1116.584} = \underline{.064}$ or only six and four tenths %. Now let us find its efficiency under the usual pressure in locomotive cylinders of 120 lbs. above the atmospheric pressure. The resistance overcome by the piston of one square foot area is now 120 lbs. × 144 = $\underline{17,280}$ lbs. in addition to the atmospheric load of 2116.8, so that the total is 19,396.8 lbs. The volume that one pound of steam will take under this pressure is 3.297 cubic feet, or the distance through which this weight is moved is represented by the distance $\underline{de}$ on the plotted curve, or 3.297 feet. The

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* Porter's Tables.

– Actual Efficiency of Steam under Pressure without Expansion. –

work done is therefore 19,396.8 × 3.297 = 63,951 ft-pounds, the excess of work done over that in the former case being 63,951. − 55,750 = 8,201 ft-lbs. The units of heat that perform this work are $\frac{63,951}{772}$ = 82.838; in the former case there being converted 72.215, the excess is 10.623 thermal units. Now the latent heat of steam at this pressure, and which does this work, is seen from the table to be 866.748 and the efficiency of the steam $\frac{82.838}{866.748}$ = .0956. But the boiling point is in this case 349.78° and the thermal units supplied to the water, 353.877 − 212.866 = 141.011° more than in the former case, and the total heat supplied by the coal is 1220.625 − 62.011 = 1158.614 thermal units equal to 894,450 foot-pounds. 894,450 foot-pounds of power supplied to the steam by the coal has resulted in the steams giving out 63,951 foot-pounds, and its actual efficiency is $\frac{63,951}{894,460} = \frac{82.838}{1158.6}$ = .071 or, seven and one tenth percent. This is all that can be got by using solid cylinders full of steam at this pressure,

– Economy in Employing High Pressures. –

and the fact is also apparent that the efficiency increases with the pressure.

The efficiency of saturated steam at this pressure, can be further increased only by Expansion. The additional distance through which it would move the piston at different terminal pressures are clearly shown on the plotted curve. Steam of 120 lbs. pressure contains a certain quantity of heat. This heat is of two forms, latent and sensible, the latter of which determines the pressure. If now we fully utilize this pressure by expansion, till the pressure is reduced to nothing*, we shall utilize only a part even of the sensible heat it contains, above the boiling point under atmospheric pressure, or

353.877 — 212.866 = 141.011, diminution of sensible heat,
965.709 — 866.748 = 98.961, increase of latent heat,
42.05 thermal units difference.

As shown by the curve, the ratio of expansion would in this case be about eight times. With this expansion and a pressure of 120 lbs. Gauge, and assuming a mean back pressure of 4 lbs. above the atmosphere, on the piston, I have calculated

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*i.e, useful pressure – above the atmosphere.

– Expansion and Condensation. Advantages of Superheated Steam in an Un Jacketted Cylinder. –

the efficiency of one pound of saturated steam expanding on the isothermal curve, by the method given by Rankine, and using his tables, and find it to increase to .12, or 12% This is never realized. The usual ratio of expansion on locomotives is about 3, that is, an average cutoff for a 24" cylinder is about 8". To obtain further the power stored up in the *latent* heat of the steam not utilized at this pressure, *Condensation*, or its change of state back into its original water, is the only way, and in the locomotive, this part, although condensation *does* actually occur, since it cools the cylinder by an amount which must be supplied by the steam entering at the next stroke of the engine, is wholly thrown away and is equivalent to the enormous amount of, at least *909,875** foot pounds for every pound of steam.

The advantages in the use of *Superheated* steam rather than *Saturated* are stated by Rankine to be, the raising of the temperature of the steam by which the efficiency is increased, diminishing its density by which *its efflux is facilitated*, and the

*(Total heat at atmospheric pressure) 1178.595 × 772 = 909,875.

back pressure lessened, and the prevention of condensation without using a jacket.

To sum up, steam is of itself inert. No power originates in it but on the contrary power is lost in the proportion that its efficiency diminishes. It is but a carrier or transporter of force. That which has been supplied to it from the heat of combustion of the fuel, is imparted more or less efficiently to the resistance at the piston in the cylinder, just as in that of any connected piece in a train of mechanism. All the force which can be obtained from it is either from its *Expansive* action, its change of state from water to steam, or its 'external work' as Mr. Porter calls it, or on the reverse of this, by its *Condensation*, its change of state from steam back to water. In both these methods of utilizing the heat which has been transferred to it, the first of which only is employed in the locomotive, the object is the same, to transform the invisible atomic motions of the steam into visible motion of masses of matter through space.

Part III.

An American Passenger Locomotive.

The Locomotive Engine is a machine for converting the expansive force of steam into mechanical work. Its ultimate object is to draw a train of a certain number of cars, upon a specified maximum up grade at a certain velocity. It consists of two high pressure steam engines mounted upon wheels, and carrying not only the apparatus for generating and distributing its power but many adjuncts for the convenience and safety of those who run it and the public at large. As it exists I have a list of over <u>two-hundred</u> parts in its anatomy alone, each having its distinct work to do and all so inter-dependant that if one fails it may involve the others in a general destruction. A complete discussion of the locomotive would, I suppose, include, at least the treatment of all of these, but it may be sufficient, in the present case, to classify its parts as follows;—

Classification of Parts.

The Locomotive.

- The Boiler, or apparatus for generating the power.
  - I. The Heating apparatus.
    - 1° The Cylindrical Shell.
    - 2° The Furnace.
    - 3°, Miscellaneous.
  - II. The Feed apparatus.
    - a. The Pump.
    - b. The Injector.
  - III. The Safety apparatus.
    - The Steam Gauge.
    - The Safety Valves.
    - The Air Brake.
  - IV. The Transmission apparatus.
    - 1°, The Throttle Valve.
    - 2°, The Steam Pipe.
    - 3°, The Exhaust Pipe.
- The Engine, or apparatus for using and converting the power.
  - I. The Cylinder and Connections.
    - The Cylinder.
    - The Cross-Head.
    - The Connecting Rods.
  - II. The Valve Gear.
    - The Slide Valve.
    - The Link and Eccentrics.
    - The Reversing apparatus.
  - III. The Running Gear.
    - The Driving Wheels.
    - The Axles and Journals.
    - The Trucks.

The Framing.

The Tender.

The Tank and Bin,

The Brakes.

—Different Classes of Locomotives.—

The differences in the construction of locomotives has produced different classes. They have hence been classified in various ways according to their use and the arrangement of their parts. With reference to their *parts* locomotives were formerly divided according to the *number* of pairs of *driving wheels* that they had, and this has been continued to the present time in the Baldwin Locomotive Works where those having *one* pair of drivers are called B engines; *two* pair, C engines, etc. Another system of classification has been according to the *position* of their cylinders, whether surrounded by the smoke-box or with outside connections, in which all locomotives were either *Outside*, or *Inside* ~~cylinder~~ connected engines. The latter class has nearly disappeared from American engines, on account of serious objections to the cranked axle necessary, which it was very expensive to make, the crowded state of the working parts, and other injurious effects

—Classification of Locomotives.—

The peculiarity in Narrow Gauge Engines.—

which have led to their disuse. With reference to their *use* or *service* we may now regard all American locomotives as of the *out-side* cylinder pattern, and classify them as either *Passenger*, *Freight* or *Shifting* which latter are often *Tank* engines. The first of these has a subvariety called *Narrow Gauge* engines in which the peculiarity is the lateral play allowed to the driving wheels, the construction of which was designed by Mr. Robert Fairlie in England and improved upon by Mr. William Mason of Taunton, Mass. The cylinders and driving wheels are attached to a truck frame which turns around a centre-pin like an ordinary truck. The front part of the boiler is hung upon a vertical link so that on passing short curves the truck very closely follows the curvature of the rails while the boiler swings over, relatively to the truck, upon the link. This constitutes an important principle

The features peculiar to each Class, – Passenger, Freight, Shifting, Tank and Narrow Gauge Engines. —

in the mounting of the engine and boiler upon wheels. These engines are, so far as I know, used exclusively for passenger conveyance. In all engines of this class, in which the maximum speed is wanted, and light loads carried compared to Freight, there is a necessity for a long wheel-base to prevent 'galloping' or 'pitching' of the engine and in the Narrow Gauge engines this is effected by a rigid connection between the engine and tender, which, while it lengthens the total wheel-base an amount equal to the distance between the rear driving wheel and rear tender wheel, does not destroy their peculiar property of passing around curves of extremely short radius. In the Freight class, great tractive power and therefore a multiplication of coupled wheels, a small diameter of driving wheels and a consequent low speed are the distinctive features. In the Shifting class, the Tank engines utilize the weight of the water and fuel by supporting it upon the driving wheels and do not work under the disadvantage of pulling a heavy tender after them. The object is to move light loads for short distances and to start them and get up speed very quickly. They have a short wheel-base which enables them to run over switches and upon sidings of very sharp curvature, and these qualities greatly overbalance the "pitching" motion which would result if they were put upon fast passenger trains.

The cost of a modern American passenger locomotive is from $8,500 to $11,000. Its ordinary 'life', ten years. Sometimes an American engine will last twenty-five years in operation, so great is the difference in the effects which operate upon them in different localities, and under different conditions. According to a paper read before the British Association the life of a locomotive is thirty years, — boiler tubes 5 years, crank axles 6 years,

—Conditions given by which to Design a Locomotive.—

tires, boiler and fire-box, 7 to 10, side frames and axles, 30 years. The total cost of repairs $24,450. so that it requires in 11 years a sum equal to its cost; and the distance it would travel in that time may be taken at 220,000 miles.

The progress in the construction of Steam engines has been in three directions, *Land*, or *Stationary* Steam engines, including the great diversity of examples in Pumping Engines for Water Works and in the portable and semi-portable types, *Marine* and *Locomotive*. Each class has its distinctive features and conditions in conformity with which the machine must be designed and under which it must work. In the locomotive, the speed, the weight of train and the grade is given from which to design and build the entire structure in all its intricate parts. The principles by which this is to be done have not yet been reduced to formulae, but the engines have been built by a process entirely empirical.

From the outset we see that we have not to do with a perfect instrument. The locomotive engine both in its mental and actual growth and as a mechanical industry has been a process of integration. Hardly an important change in theory has been made in the engine since Stephenson's time. The details, by the immense advance of the processes of manufacture, by the improvement of machine tools, have been minutely examined and improved until we have, seemingly, as perfect a practical exhibition of theory as we can hope to attain. But in this improvement of detail the engine has been perfected, as we have seen, to an extent far beyond that of the boiler. The tendency of all first inventions is complexity. Inventors are often far more ingenious in making a machine that will do a diversity of operations many of which are superfluous to the object at hand, than in producing simplicity. One of the first requisites of the production of power is economy. Every superfluous part added increases the cost, first, by the material wasted, the expense of machines made to produce the part, the labour of fitting and skilled workmanship; and second, by the expense of looking after and repairing it and the constant and greater part by the force consumed in running, the friction, etc. Hence in such a machine as we are considering one would think that as we improved we would simplify until the limit is reached when only the essential parts of the mechanism to fulfil the definite and specific object for which the machine is to be employed, are used. This does not seem to be the case, thus far, however, in the example before us. As a whole it is complex although we can not say that any one part is superfluous, at the present time, because nothing better and more simple can be substituted for it. The parts have increased, some in the moving mechanism, some for safety and signals, such as the Westinghouse Air or the Vacuum Brake, the bell, whistle etc, and others for convenience, and this is not to be regretted.

In all improvement in design of the locomotive engine, then, existing examples have been taken as the basis and the proportions of a new one founded, with certain modifications according to the kind of service for which it was to be made, entirely upon estimates from the experience of the designer, and hence by a kind of guesswork.

By reason of these facts it was thought that the best mode of treating the subject was to select a good pattern of locomotive, which, having its parts and proportions already given, the reasons for these proportions could be studied and their conformity to theory, in so far as that has been applied to the locomotive, ascertained. For this purpose I have selected a first class bituminous coal burning <u>Passenger</u> engine for a rather heavy passenger service and built at the Hinkley Locomotive Works, in Boston. This engine is of the four driving wheel and swing truck pattern, was designed and built in the latter part of 1875; for the Eastern Railroad Company and is now running on one of the fast Pullman trains on the road. It was selected both on this account and for convenience and as being a fair type of the coal-burning engines running on the New England Roads.

The process of proportioning a locomotive will be applied to this example. It becomes now our object to apply theoretic principles to this particular engine and determine what its performance should be. In the succeeding part it is the intention to ascertain how nearly it does approach to this theoretical excellence and so to determine its actual efficiency. Let us then see if the limit of perfection attainable has been reached and if, as Mr. Bourne believes, we must look in the fire ture to some other agent of power than steam, such as air, in order to further augment its efficiency.

The dimensions and detail drawings accompanying will obviate the necessity of an extended description of parts and hence they will be further described only incidentally.

To illustrate the parts of this engine five drawings have been made a list of the details shown in which, is given at page II. They were traced from drawings made at the Hinkley Works and published in Weissenborn's 'Locomotive Engineering'; and show nearly all the important parts. The details are correct and will be often referred to, although the design is for a heavier engine than that we are considering and hence most of the dimensions given are too great.

The following is a complete specification of this engine, obtained, with care taken in regard to its correctness, both from the specification in the books at the Hinkley Works and from actual measurements of the parts;—

Specification
of a
Locomotive Engine
for
The Eastern Railroad Company.

Oct 25th,-1875.

From the
Hinkley Locomotive Works,

Boston, Mass.

Boston, Oct, 25th, -1875.

SPECIFICATIONS OF LOCOMOTIVES

One Eight-Wheeled Heavy Engine & Eight-Wheeled Tender

FOR THE

Eastern Railroad Company.

GENERAL DESCRIPTION.

To be first-class coal burning Passenger engines, having four driving wheels coupled, a four wheeled centre bearing truck and eight wheeled tender.

All working parts thoroughly interchangeable, and all material warranted of the best quality.

Diameter of Cylinders, ... 16 inches.
Length of Stroke, ... 24 "
Diameter of Driving Wheels, ... 62½ "
Total Wheel Base, . . . 21 feet 4½† "
Centers of Driving Wheels, . . 7 " 7-6 "
Weight of Engine with fuel and water, . 63,000 lbs.
Capacity of Tank, ... 2500 galls.
Gauge of Road, ... 4 feet 8½ inches.

DETAILS.

BOILER. Shell wagon top, of extra flange charcoal iron thoroughly stayed and riveted throughout, and having one dome. Throat sheets and all horizontal seams double riveted. Fire Box of homogeneous cast steel thoroughly stayed to shell and dome. Shell of boiler flanged up into dome. Smoke Arch raised up even with lagging by one inch bar.

Inside diameter of Shell, ... 48 inches.
Diameter of Dome, ... 28 "
Length of Fire Box, inside, ... 60 "
Water Space, ... 3 "
Centers of Stay Bolts, not over . . . 4 "
" Crown Bars " . . . . 4½ "
Number of Tubes, ... 161.
Diameter " . . (Outside Diam.) 2 inches.
Length " . . . . 11 feet 0 "
Thickness of iron in Shell, . . . 3/8 "
" steel in Sides and Back of Fire Box, 5/16 "
" " in Tube Sheet, . 7/16 "
" " in Crown Sheet, . . 5/16 "

FRAME, of hammered scrap iron, forged solid, with lugs to hold cylinders. End rails wrought iron.

CYLINDERS, of fine hard iron, placed horizontally, and bolted to frame and smoke arch in the most approved manner.

Cylinder oil cups placed in cab with seamless brass tubes under lagging to steam chests. Oil cups also on steam chests.

Length of Steam Ports, ... 14 inches.
Width " " . . . . . 1¼ "
" Exhaust " . . . . . . 2⅜ "

DRIVING WHEELS. Centers of cast iron, with hollow spokes and rim. Tires of best (Krupp) cast steel, all flange. Axles of hammered iron.

Diameter of Centers, of wheels (cast iron) 57 inches.
Width of Tire, ... 5¾ "
Thickness of Tire, ... 2¾ "
Length of Journals, ... 7 "
Diameter " . . . . . . 7 "

CRANK PINS, of steel.

TRUCK. Frame of wrought iron forged solid. Jaws of cast iron. Wheels cast steel rims, N. Washburn's patent.

Length of Truck Journals, ... 7 inches.
Diameter " " . . . . . . 4½ "
" " Wheels, ... 28 "

VALVE MOTION. Links of hammered scrap iron, thoroughly case hardened and made to cut off equally at all points of the stroke. Rockers and Reverse Shafts forged solid.

Centers of Links, ... 12 inches.
Travel of Valve, ... 5 "
Diameter of Rocker Shaft, ... 3½ "

CROSS HEADS AND SLIDES. Cross Heads of charcoal iron cast in dry sand. Slides of steel.

YOKE, of hammered iron, reaching from frame to frame.

PISTON PACKING, of two composition rings babbitted.

PUMPS. One in number, of composition. Valves of hard composition.

INJECTOR. One No. 6, Mack's.

SAFETY VALVES. Two in number. Richardsons Pat.

SMOKE STACK. coal burning.

GRATE. for coal burning.

CAB, of Bl. Walnut well joint-bolted. Roof covered with tin.

PILOT, of wood well braced and ironed.

WHISTLE. Worked by shaft and lever in cab.

FINISH. Boiler lagged with wood and covered with Russia iron, secured by finished brass bands. Cylinders lagged with wood, and covered with brass Head of cast brass Steam Chest trimmings of brass Dome and Sand Box covered with brass Mouldings of brass.

SUNDRIES. Each engine to be furnished with steam gauge; gauge, heater, blow-off, and water-cocks; also, oil cans, two jack-screws, two pinch-bars, wrenches, hammers, file, boxes, &c.

TENDER. Tank of best tank iron, well braced.

Wheels 30" chilled iron. Cast steel elliptic springs.
Frame of wood.
Capacity of Tank, . . . 2500 galls.
Thickness of iron in bottom and inside of legs, ¼ inches.
" " top and sides, . . 3/16 "

PAINTING. All unfinished work of engine and tender to be neatly painted and varnished. Boiler to have a coat of mineral paint under lagging.

BOSTON, Oct — 1875.

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† From actual measurement.

SPECIFICATIONS

OF

LOCOMOTIVE ENGINE

FOR THE

THE HINKLEY LOCOMOTIVE WORKS,

439 ALBANY STREET,

BOSTON.

THE HINKLEY LOCOMOTIVE WORKS,

MANUFACTURERS OF

L CLASSES OF LOCOMOTIVE ENGINES,

Boilers, Tanks, Iron and Brass Castings.

439 ALBANY STREET,

BOSTON.

s AYER, President.
BULLARD, Treasurer.

H. L. LEACH, Gen'l Manager.

F. D. CHILD, Sup't.
GEO. F. CHILD, Sec'y.

Additional Facts.

Boston, Oct 25th, 1875.

For the Eastern Railroad Company.

Name, ... none. Road Number, 55.

Shop Number, 1225. To be Delivered

Date of Delivery, Oct 28th, 1875.

Cylinders, 16"×24", brass lagging, Drivers, 4 in num. color black, gold stripe.

Tires, 2¾" thick, 57" inside diam, all flanged, Firthe's steel-imported.

Boiler, 7" wagon top, 88" height back end, 40½" height of door. Iron, ½" thickness of front tube-sheet.

Dome, one on furnace 28" di, none on shell, brass lagging.

Flues, 161 in number, of iron 11'-0" long, 2" O.D, ⅝" water spaces.

Fire-box, Baystate steel, 60" long, 66" high, 35⅝" wide inside. Tube sheet 7/16" thick.

Frame, Front rail 3½" deep, 3" wide. Back rail, 3½" deep, 3" wide, 9" offset, 18" jaw.

Truck, Centre bearing, Truck wheel base 5'-6"+, Frame 48⅞" wide, 1¼" iron. Wheels, steel rim.

+ From actual measurement.

Rods, Main, centre to centre, 7 feet, 4 3/8 inches.[+]

Parallel, " " " 7 " 6 "[+]

Crank Pins, Bearings, 3 13/16" × 4", & 2 13/16" × 2 3/4".

Ports, admission, 14" × 1 3/4". Offset face 3 1/2".

Valves, 5" motion, 7/8" outside, 1/32" inside lap.

Links, 60" radius, 12" centres, 13 3/4" lifters, Pin 3/8" back.

Eccentrics, 5" throw, 13 13/16" diam, 3" thick. Straps ×.

Pump, One right Plunger, brass, 1 7/8"[+] diam, brass vacuum chamber.

Injector, One #6 Mack's, over running board and taking water back of rock.

Check Valves of brass, covered with brass.

Rockers, of Wrought iron, 3 1/2" diameter. Arms 9 1/2" long.

Slides, 45 1/4" long, 3" wide, 1 1/2" thick.

Piston Rods, 34 1/8" long between shoulders, 2 5/8" diam.

Packing, Dunbar, iron cut into six pieces.

Cross-heads, solid.

Whistle, 6" diam. Shaft in cab.

Throttle, 5", Puppet.

Steam Pipes, Dry pipe 5 5/8" inside diam. Branches 4 1/2" diam. of Cast iron.

[+] From actual measurement.

Driving Boxes, regular, 7" x 7".

Valve Stems, bushed with socket and key.

Safety Valves, two in number, 2 1/4" diam. No levers.

Sand-box, 28 pattern. Covered with brass, cast brass [rings.

Bell, Large pattern. Posts of iron.

Smoke Stack, 13 feet, 8 inches high from rail.
coal burning, 38" netting, 61 1/2" high, of Cast iron.

Cylinder Oil Cups, on chest and gauge stand.

Grate, coal burning, 60" long, Eastern R.R. pattern.

Cab, Black Walnut, 63 7/8" long.

Pilot, Wood. Vertical Slats. Iron broom stands, E.R.R.

Tender, Tank (See Part V.) Wheels, 8 in number,
Washburn Iron Co, Draw casting, Miller's new
pattern, Axles, E.R.R.

Springs, Driving, Nichols, Pickering & Co, Pittsburg
E.R.R, 11 leaves, Truck, N.P.&Co, 16 leaves.
Back Tender, N.P.&Co, Rocker 17 leaves.
Front Tender, " " " " "

Remarks;— Used low casting with long foot for Reverse lever heel.

Lazzy Cock with shaft & wrench through foot-board.

— Mode of Considering the Boiler and Engine. —

Air Brake Pump on left side between wheels. New pat. pump. Cylinder cocks worked with straight rod and lever in cab.

Exhaust Nozzle and tips double, 3 1/4" di; E.R.R. pattern. Tender Springs set up on Shoes 2" thick. Grate area and Heating Surface will be calculated farther along.

The details and action of the Locomotive, following somewhat the order of the preceding classification, may be regarded in the following way; —

A. The Boiler, I. The Shell, construction, material, Strength, Factor of Safety.
  II, The Heating Apparatus and Boiler Proportion.
  III, The Feed Apparatus.
  IV. The Safety Apparatus. And
  V, The Transmission Apparatus, or the Distribution of the Power to the engine.

B. The Engine, I. The Cylinder and its proportion.
  II. The Valve Gear.

III. The Action of Steam in the Cylinder and the Theory of the Blast.

IV. The Transmission of Power to the Wheels by means of the Crank and Connecting Rods.

V. The Running Gear.

VI. The Balancing of the Engine. And

VII. Tractive Power and Train Resistances.

In each of these, as far as we shall be able to enter upon their discussion, it will be the endeavor to trace the power as it is transmitted from one piece of mechanism to another.

The Boiler of a Locomotive Engine is a close vessel in which steam is generated,* and it has these distinct parts, the cylindrical shell called the barrel or boiler proper, the internal and external firebox attached to it and the smoke-box upon which rests the chimney or smokestack. It is made up of several sheets of wrought iron, and in the internal fire-box, steel; of irregular shapes, bent to their proper form and riveted together by the system of single riveting except in the longitudinal seams which are double riveted. The names of these

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*Wilson.

sheets or plates, referring to the position in the boiler which each occupies, are,—the Shell plates, Off-set plates, Side plates, Bottom plate, Front Round Head, Front Tube plate, Back-head, Front Furnace plate, Crown Sheet, Dome plate, Side plates, Tube plate, Ash pan, bottom and side plates, Door, and two Smoke Arch plates.* The boiler proper, is a cylinder, 11 feet long and 48 inches in inside diameter, and made up of three cylindrical sections. Each of these sections is formed from a single plate, 56" in breadth, and 15' 6½" long, which wraps entirely around the circumference of the boiler. The ends of this plate are riveted together and constitute a longitudinal seam in the boiler. The ends of the three sections which constitute the boiler shell, overlap, one upon another and are united by a single row of ~~diagonal~~ riveting, around the circumference. In putting the sections together they shut one within another, not, like the tubes of a telescope, but alternately over and under the edge of the section adjacent, so that the diameter of alternate sections is greater, by twice the thickness of the plate, than that of intervening ones. Connecting the cylindrical barrel of the boiler to the rectan-

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*I have the dimensions of each of these plates, technically named above, before me, but it is thought unnecessary to insert them.

gular fire-box with its hemispherical top are diagonal plates shown in Plate A at a Fig 1, and four in number called the Offset Plates, which increase the radius at the fire-box end of the outer shell, by 7 inches. The under plates are bent so as to form flanges upon which to rivet the perpendicular front side of the external fire-box. The barrel of the boiler consists of the outer shell which has at its two extremities the two tube-plates placed eleven feet apart and connected by 161 tubes, each 2 inches in diameter; the smoke-box which is simply an extension of the shell by an additional section forming a receptacle for the hot gases as they come in detached currents from the fire-box through the tubes; the bracing, which consists of ten longitudinal stay rods passing from the front tube sheet to the back end of the boiler, through the steam space above the tubes, and fastened by nuts and washers upon the outside, diagonal stays for the ends, and angle iron; and the lagging which consists of felting and wood covered with russia iron and held down by bands of brass running around the boiler.

— Desirable Qualities in Steam Generators —

The qualities which it is most desirable to fulfil in the construction of the steam generators of locomotives are; Adaptation to the circumstances of their use;* Durability, or economy in the expense necessary to keep the boiler in repair; Economy in construction, in material and workmanship by which weight would be reduced to the limit of that required for adhesion; Strength, to sustain both the internal pressure and other sudden forces coming upon it, and thus to insure safety; and sixth, Efficiency, or economy in evaporative qualities, to decrease the cost of maintenance, to produce more power without increase of weight, and to employ as thin heating surface and as great in extent as possible without influencing in an injurious way the other conditions. How nearly the locomotive boiler fulfils these conditions would form too great a subject for discussion here and we will hence take up in a general way only the problem of boiler strength and efficiency. The material in use for locomotive boilers is Wrought iron, and Copper or Steel for the fire-box. The advantages of copper are soundness— easy working— little corrosion or oxydation— ductility in working and flanging, and its superior conducting

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* Trowbridge.

power to iron. Its disadvantages are its cost, softness in resisting the particles of coal driven against such parts as the crown sheet or tube plate, its loss of strength on being heated and the greater thickness required for strength which off-sets its superior conducting power. The unequal expansion also of two metals used together has an important influence. Wrought iron has many advantages and but few defects, the greatest of which is its rusting. It is perfectly reliable which cannot as yet be said of steel, for the unaccountable way in which that, apparently of the best quality, cracks in the fire-boxes when the boiler is cooling down, separating sometimes through the rivet holes but often diagonally or between them, has formed a subject for almost endless discussion. Wrought iron increases in strength on heating up to 570°,* and its properties as well as those of steel in this respect are best shown by the tables inserted which give the facts concerning the metals that are used in the locomotive under consideration. The iron and steel for this locomotive was furnished to the Hinkley Works on the authority of these experiments, and was not tested by them before being made up into the boiler. The ultimate tenacity

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*Expts. by Franklin Institute.

Experiments on Tensile Strength of Boiler Plate,

MADE BY

C. B. RICHARDS, ESQ., M. E., HARTFORD, CONN.,

(Member of American Society of Civil Engineers).

TENSILE STRENGTH OF BOILER PLATE.

TABLE IV.—Showing the Effect of the Shape of the Specimen on the Result, for "Bay State" Flange Plate.

Number of Specimens tested.	KIND OF IRON AND ITS BRAND.	Nominal Shape of the Specimens.	Direction of the Strain relatively to the Direction in which the Plate was rolled.	Approximate Dimensions of the Original Cross Sections.	TENSILE STRENGTH PER SQUARE INCH.					Reduction of Area of Cross Section at Place of Fracture, measured after Fracture.	Ultimate Elongation referred to Original Length.
					Original Cross Section.				Fractured Cross Section.		
					Strongest Specimen.	Weakest Specimen.	Averages.	General Averages.			
				Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Per Ct.	Per Ct.
6	Bay State, Flange	Long.	Lengthwise.	1.25 x 0.29	47785	46484	47017	47450	64411	27.0	19.3
3	Do.	Do.	Crosswise.	0.75 x 0.29	49113	46815	47884		56755	14.0	12.1
6	Do.	Short.	Lengthwise.	1.25 x 0.29	52993	50770	51943	52102	61295	15.3	....
3	Do.	Do.	Crosswise.	0.75 x 0.29	53161	51597	52262		58170	10.2	....

TABLE V.—Bay State Plate in "Long" Specimens.

Number of Specimens tested.	Kind of Iron and its Brand.	Nominal Shape of the Specimens.	Direction of the Strain.	Approximate Dimensions.	Strongest Specimen.	Weakest Specimen.	Averages.	General Averages.	Fractured Cross Section.	Reduction of Area.	Ultimate Elongation.
14	Bay State, Flange	Long.	Lengthwise.	1.25 x 0.30	51378	44036	48098	47187	63596	24.8	16 2
12	Do.	Do.	Crosswise.		49023	39898	46277		52349	10.7	10.7
4	Bay State, C. No. 1	Do.	Lengthwise.		48819	46086	47725	46013	55967	14.5	11.5
4	Do.	Do.	Crosswise.		45240	42961	44301		48849	9.2	6.5
4	Bay State, Homogeneous Metal	Do.	Lengthwise.		71139	70100	70672	.....	136473	52.0	20.0

TABLE VI.—Various Kinds of Plate in "Short" Specimens.

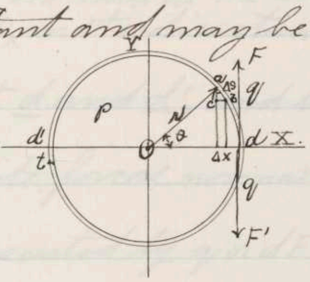
Number of Specimens tested.	Kind of Iron and its Brand.	Nominal Shape of the Specimens.	Direction of the Strain.	Approximate Dimensions.	Strongest Specimen.	Weakest Specimen.	Averages.	General Averages.	Fractured Cross Section.	Reduction of Area.	Ultimate Elongation.
2	Thorneycroft, English (from an old boiler),	Short.	Lengthwise.	0.87 x 0.27	47245	46410	46827	45293	49700	....	.....
2	Do.	Do.	Crosswise.		44355	43165	43760		45000	....	....
3	Pennsylvania, "Common,"	Do.	Lengthwise.	0.87 x 0.16	54699	44581	49227	48434	55604	....	....
3	Do.	Do.	Crosswise.		54031	43436	47641		50000	....	....
3	Pennsylvania, C. No. 1	Do.	Lengthwise.	0.87 x 0.28	56429	53870	52986	53646	57600	....	....
2	Do.	Do.	Crosswise.		55218	53395	54306		60700	....	....
1	Pennsylvania, Flange	Do.	Lengthwise.		.....	.....	54466	53733	70600	....	....
2	Do.	Do.	Crosswise.		54819	51184	53001		57400	....	....
10	Bay State, C. No. 1	Do.	Lengthwise.		58450	48650	53129	52528	.....	....	....
4	Do.	Do.	Crosswise.		53145	50449	51928		.....	....	....
4	Bay State, Flange	Do.	Lengthwise.		57934	54377	57529	55612	.....	....	....
2	Do.	Do.	Crosswise.		53998	53395	53696		.....	....	....
2	Sligo Fire Box	Do.	Lengthwise.		53791	52546	53168	52750	67100	....	....
2	Do.	Do.	Crosswise.		54394	50272	52333		56400	....	....
1	Do.	Do.	Lengthwise.	1.25 x 0.33	.....	.....	60911	.....	81700	....	....

of these two metals, then, may be safely taken at the figures underlined in red, or

Ultimate Tenacity of Baystate Extra Flange Iron, 52,102 lbs. per [square inch.

" " Homogeneous Steel , 70,672 "

The formula by which to calculate the strength of the cylindrical shell of a steam boiler, though very simple, is extremely important and may be thus deduced*;—



Let the figure represent a section or ring of the boiler, whose internal radius is r", thickness t, in fractions of an inch and its length perpendicular to the plane of the paper, 1", or unity. Let the thin hollow cylinder be under an internal pressure, the intensity of whose stress is p, pounds per square inch. And let f be the ultimate tenacity of the material. This stress, p, is everywhere normal to the circumference and the lines which represent its direction, of which there would be an infinite number, all radiate from O. The resistance of the material to this stress acts everywhere perpendicular to the direction of the stress p. or tangential to the circumference.

[*] There are a number of ways of proving this, one method is given by Forney, another by Weisbach, Prof. Lanza another, and Rankine a different one still.

Consider the stress resisted by the cross section at d, and d'. Now the stresses along the horizontal axis X, in both directions from O do not tend to burst it. At d and d', the horizontal stresses tend to push out the lower half just as much as the upper, and there is no tendency to slide one crossection by the other. Only the vertical stresses upon one half of the shell, in the direction OY, tend to separate the cross sections at d and d'; and they are resisted by equal and opposite forces normal to these horizontal sections and represented by q or dF, dF'. Now for any intermediate direction let the stress p, be represented by the line r which makes any angle α with OX. Only its vertical component, $p \sin \alpha$ acts, and the total stress is the sum of all these components acting upon the circumference from d to d' on the upper segment, or $P = \Sigma \cdot p \sin \alpha$. Each of these stresses acts on a unit length of cylinder and on a short arc in the circumference Δs. Let fall from a and b perpendiculars on OX, and draw $bc \parallel OX$. ab is, for so small an arc, practically $\perp Oa$ $\therefore$ the angle at $a = \alpha$. Now $\sin \alpha = \frac{bc}{ab} = \frac{\Delta x}{\Delta s}$ $\therefore P = \Sigma \cdot p \cdot \frac{\Delta x}{\Delta s}$ and integrating x between the limits d and d', the arc drops out, $\int_{-r}^{r} p \frac{dx}{ds} ds = px \int_{-r}^{r} = pr - (-pr) = 2pr$ .... The thickness of metal to resist this total stress at d and d' being t, its area is $t \times 1$, and the strength being f, the total resistance of the material = 2ft $\therefore \cancel{2}pr = \cancel{2}ft$, $pr = ft$, $p = \frac{ft}{r}$, $t = \frac{pr}{f}$, $r = \frac{ft}{p}$.

To find the strength of the sections in resisting the pressure upon the ends, as upon the tube plate, we have the pressure $P = p \times \text{Area} = p \cdot \pi r^2$. The resistance is that of the whole circular cross section to resist rupture, or $\pi(r+t)^2 - \pi r^2 = 2\pi r t + \pi t^2 = 2\pi r t\left(1 + \frac{t}{2r}\right)$. Now, as the ratio $\frac{t}{2r}$, of the thickness to the diameter is a very small fraction, in this case being $\frac{3/8}{48} = \frac{1}{128}$, it is neglected and the resisting area can be assumed to be represented by a rectangle of the length $2\pi r$ and width t, and multiplying by f, we have the resistance, $2\pi r ft$, or $\pi r^2 p = 2\cancel{\pi}\cancel{r}ft$, $\therefore$ $pr = 2ft$, $p = \frac{2ft}{r}$, $t = \frac{pr}{2f}$, $r = \frac{2ft}{p}$, or the pressure upon the ends may be twice as great as in the former case. In these formulae the assumption is made that the stress is uniformly distributed over the cross section, which is only approximately true for thin shells. In the case of a sphere we have the latter case for every diametral section and hence the sphere is the strongest of all known forms for steam boilers. It also contains the greatest volume within a given amount of surface or material. As far as strength alone is concerned boilers should have the spherical form. To ascertain the reduction of strength due to the rivetted joints,

—Strength of Riveted Seams;—

there are a number of easily deduced formulae giving the relation between the diameter of the rivet, the thickness of the plate and the pitch of the rivets. The weakness of the joint may exhibit itself in a number of ways, by the plate in front of a rivet crushing, by the rivets shearing, the plate tearing between the rivet holes, the plate splitting from the rivet hole to the edge, or the plate forced out by a wedge like action of the rivet, all of which have to be determined in obtaining the greatest strength attainable with our present system of rivetted boilers. In this connection it may be remarked that an important improvement in the locomotive engine, in the safety of the boiler, the cost of construction and maintenance, and its efficiency will be made when *seamless* or welded *steel boilers* are practicable, a hint of the practicability of which has already gained ground. It being impossible to trace through, these deductions within our limits, although they are interesting and important, the strength of the double rivetted plate along the rivet holes, as deduced from Sir. Wm Fairbairn's experiments, by Wilson in his 'Treatise on Steam Boilers', correcting for the loss of strength due to the treatment of the iron, the diminished section through the line of rivets and the excess of strength in long over short lines, is 70% of that of the plate. The rivets in this boiler are* $^{11}/_{16}$" diameter, heads 1" diameter × 3/4" high, set, the first row 1 1/4" from the edge of the plate, the second 2 1/4", and the pitch 2" or 1 $^{15}/_{16}$". We may now determine the boiler strength. Applying the formula, $f = 52,102$, $t = 3/8"$, $r = 24"$ ∴ the ultimate or bursting pressure $p = \frac{f \times t}{r} = \frac{52,102 \times 3/8}{\underset{8}{\cancel{24}}} = 814.1$ lbs per sq. inch. 70% of 814.1 = 569.87. Now to determine with what factor of safety this locomotive is running, we have the usual steam pressure, 140 lbs, often running up to 144 or 5, and it being not improbable that from a slight cause it would reach 150, (See Part V), $\frac{569.87}{150} = 3.8$, or at 140 lbs the factor of safety is but 4. If it were not for constant attendance this would be rather hazardous, and 6, as given by Rankine and Wilson would be the better figure. It indicates the great difference between the factors of safety of the parts, the mechanism in some parts having as high as 30, while the positive, live force of steam has but 3 or 4. Again, from the wearing or corroding of the plates they become thinner, the usual rule being to deduct 1/5th for deterioration after several years, and this is allowed for by reducing the working pressure, perhaps 20 lbs. and running

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* From measurements.

— Collective Pressure. —

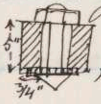
at 120 lbs. making of the locomotive a Second Class Engine. It is unnecessary to calculate the strength of other parts, such as the tube sheets which are thicker and heavily stayed, the fire-box flat sides, for these are determined by other considerations, stiffness & resistance to bulging. The invariable rule is that the stays shall not be more than 4" apart, and they are usually twice the thickness of the plates in diameter. In the flues the tendency of pressure is the opposite of that on the shell. While in the latter case, the internal pressure tends to make the shell a perfect cylinder, in the flues, a slight distortion is further increased by pressure, but from their small diameter the effect of the compressive force upon them is not in general equal to that on the shell. The collective pressure inside a locomotive boiler is immense. To obtain some idea of what it would be the calculation was made for the shell alone. Its volume exclusive of the tubes is very nearly 100 cubic feet. The square feet of surface in the shell is 138.23, on the tube plates, after deducting the area of the tubes, 9.05, and on the tubes, 927.3. On every square inch of this there is a pressure of 140 lbs. or 20,160 lbs. upon the square foot. So that on the shell alone it amounts to 2,786,717 lbs, on the tubes alone, 9,344 tons and the total upon the boiler is

— Stress caused by Attachments and Expansion —

10,740 tons. But there are other forces much more violent than this which the locomotive boiler has to daily withstand. It has been stated that the boiler is the back bone of the locomotive engine. Upon it are placed many attachments, it is cut up by large holes and most of the sheets punched for stay bolts, braces and outside attachments, whose weight alone tend to ~~greatly~~ distort it. Then there is the force of expansion, very unequal in different parts. On ~~getting up~~ raising steam in this boiler it lengthens from 7/16 to 1/4" at the fire-box end where it is free to expand. Formerly no allowance was made for this in bolting it to the frame and the immense stress thus produced caused it to rise in the middle, partially counteracted by the weight of the water which in this boiler with two gauges is over 3,126 lbs or over a ton and a half. At the fire-box end the frames are supported in straps which permits the boiler to slide along the frames during expansion. The frames are 1/2" from the sides of the fire-box and notwithstanding the fact that the expansion must be greater inside the fire-box from the high temperature, the external fire-box is found to expand 3/32" inch towards the frames. As a whole, the apparently rigid boiler is not so in reality. It is yielding in every direction. ~~If it were~~

— The Furnace. — The Heating Surface. —

~~not, theoretically, it could not pass our ordinary gauge.~~

The Furnace in a locomotive consists of the External Fire-box whose parts ~~are~~ include the furnace door, the ash pan and ash pan dampers; and the Internal fire-box whose parts are the grate, the crown sheet, crown bars and furnace stays). The furnace is strengthened on its large flat surfaces by the stay bolts screwed into each plate and riveted upon the ends, and which are sometimes made hollow both to admit air to the gases above the fire and to give warning by leakage when they become useless from corrosion. The crown sheet is strengthened by double crown bars of the dimensions given , placed 4½" apart. Two are ~~[illegible]~~ made in one piece being joined at the ends, and they are attached to the crown sheet by bolts passing between them as shown. The crown bars are set off from the plate by smooth circular washers ½" thick, which allow for circulation of water around them beneath the crown bars over ~~upon~~ the surface of the plate.

The Heating Surface[11] includes all the internal surfaces of the boiler exposed to the hot gases upon one side of the plate and in contact with the water upon the other. The amount of heating surface is practically limited only by the size of the boiler. The more that can be introduced in it the greater the available heat, of the total produced

— Usual Proportion. — Calculation of Heating Surface. —

by the combustion of the coal. The usual proportion to grate area is 50 square feet for each square foot of grate. The dimensions of the fire-box of this engine, ~~taken from~~ it will be seen by the specification are 60" length × 35 5/8" wide × 66" high, the metal in the sides and back and in the crown sheet being 5/16" in thickness, and that in the tube sheet 7/16". The grate area is therefore 60" × 35 5/8" = 5' × 2.9687' = 14.84 sq. feet, and by the above rule the total heating surface should be 14.84 × 50 = 742 square feet.

The actual heating surface is as follows; —

Heating surface in tubes = $2\pi r \times l \times n$ = 6.2832 × 1" × 132" × 161 = 829.38 square inches × 161 = 5.7596 sq. ft. × 161 = 927.2956 sq. feet.

Heating surface in Fire-box. Back end, 2.9687' × 5.5' (ht.) − 1.3893 sq. feet (area door, 18" × 15") = 16.3259 − 1.3893 = 14.9366. Front end, 16.3259 − 3.5098 (area of tubes in square feet, = $\pi r^2 \times n$) = 12.816 square feet. Sides, 2 × 5' × 5.5 = 55 sq. ft. Crown sheet, same as grate area, 14.8435 sq. ft.

The area of heating surface in the front tube plate = area cross section of shell − area of tubes = 12.5664 − 3.5098 = 9.05 square feet, and neglecting this since it is practically of no value as heating surface, except to maintain the heat already in the water,

— The Efficiency of the Heating Surface and Furnace. —

on account of the low temperature of the gases in the smoke-box, the total heating surface may be expressed as follows;—

Total Heating surface in Fire-box, 97.596 square feet.
" " " " Tubes, 927.295 " "
Total in Boiler, - - - - - - - -1024.89 square feet.

The Efficiency of the Heating Surface is the ratio of the difference of temperature of the hot gases on first coming in contact with it and on leaving it, to the amount of heat transmitted by it to the water, or calling T_1 the temperature of the hot gas at first, T_2 its final temperature, and t the temperature of the water, its efficiency is $e = \frac{T_1 - T_2}{T_1 - t}$. The efficiency of the furnace is the proportion that the available heat from one pound of fuel bears to its total heat of combustion. The laws of combustion we have seen are fixed and definite and the boiler should be so proportioned as to conform to them. With ~~we come to~~ the heating surface, however, it is found that no two portions have the same efficiency. The latter depends upon a number of conditions, — the extent of surface — its position — the nature and thickness of the conducting material — the difference of temperature — the time allowed for the transmission —

—All parts of the Heating Surface have not the same Efficiency—

the nature of the heating substance whether heated gas, flame or incandescent fuel, and the manner in which the heat is communicated, by conduction or radiation. In regard to the first two of these it has been found* by Mr Armstrong that "a cubical metallic box, submerged in water, and heated from within, generated steam from its upper surface more than twice as fast per unit of area than it did from the sides when vertical, and that the bottom yielded none at all." From this experiment and others by C. W. Williams and D. K. Clark upon the diminished heating effect of successive portions of the tubes, it is found that the crown sheet and furnace tube plate are the most efficient, a square foot of the fire-box area being equivalent to three, of the tubes. The latter are placed in vertical rows with 5/8" water spaces between them, and from the above, it will be seen that the bottoms of the tubes, or 1/4 of their circumference have practically no heating effect, while the sides together are only equal to the top, so that as a whole we may consider but one half of the tube area is really as effective as the fire-box. The equivalent heating surface in the tubes would therefore be but 463.6 square feet instead of 927.3. Practically, in estimating the heating surface, 3/4 of the tube area is included, neglect-

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* Tredgold on the 'Steam Engine'

— Rate of Conduction. —

ing only the bottom, so that in this boiler we may correct the total heating surface found, and by doing this we have the effective heating surface $= \frac{3}{4} \times 927.295 + 97.59 = 695.47 + 97.59 =$ 793. square feet total, which agrees very well with that given by the rule, or 742. Assuming that the hot gases escape at a temperature of 600° which is the maximum, and also the temperature which would produce the best natural draught,* the rate of conduction through a square foot of this surface may be found by the formula deduced on page [illegible]§, or $K = \frac{(T'-T)^2}{180} = \frac{\{3044 \text{ (temp. of fire page 36)} - 600\}^2}{180 \text{ (mean value)}} = 33,184$ thermal units per hour. Or, if the heat was fully utilized, since the temperature of the escaping gases cannot be lower than the temperature of the water, and this for 140 lbs steam pressure, as given by the Table page, 55, is 360.596, the rate of conduction could not be more than $\frac{(3044-361)^2}{180} = 39,436$ th. units.

The efficiency of the entire heating surface obtained by integrating the value of $\frac{T_1 - T_2}{T_1 - t}$ for each portion dS, of the square feet of heating surface, can be proved† to be equal to this expression given by Rankine, $e = \frac{S}{S + \frac{a c'^2 W^2}{H}}$ in which a is a constant, c' the specific heat of the gas at constant pressure and W, the weight of gas given out in an hour, H, the total expenditure

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* Can be proved as in Rankine's "Steam Engine."

† The proof by the Calculus is rather complex and too long to introduce here. It is deduced by the use of Peclet's formula given [at page §

§ Demonstration of formulae omitted.

of heat per hour, and S the square feet of heating surface. The efficiency of the furnace, or the ratio of its available to the theoretic evaporative power of the coal is represented by an equation of the form $e = \frac{E'}{E} = B \frac{S}{S + AF}$* in which F is the number of pounds of coal burned per hour and with S, may be taken <u>per</u> square <u>foot</u> of <u>grate</u>, A = .3 and B, is a fractional multiplier to allow for miscellaneous losses, & which with the best connection and forced draught is unity, but for ordinary connection is $^{19}/_{20}$, 5% being deducted for these losses. The maximum rate of combustion in locomotives is 125[†] lbs ([†]Forney) of coal per square foot of grate per hour $\doteq$ F. S, when the maximum or total amount of heating surface is used $= \frac{1025}{14.84 \left(\frac{\text{grate}}{\text{area}}\right)} = 69.2$. The ratio, $\frac{S}{F} = \frac{69.2}{125} = .55$ and the corresponding efficiency .59.

The corresponding evaporative power from 212°, in which case the total theoretic evaporation, E, is found to be 13.82 lbs, from Table IV page 36, is $E' = E \times e = 13.82 \times .59 = \underline{8.15}$ lbs of water. From 62°, and at atmospheric pressure, the evaporative power is $11.97 \times .59 = 7.06$ lbs of water. Another way of calculating the efficiency of the furnace is from the temperatures, $\frac{T_1 - T}{T_1} = \frac{3044 - 600}{3044}$, which gives 80% for its efficiency, but this is a theoretic method and the actual in no wise approaches it. The more actual case, it seems to me, would be to take the effective heating surface, 793, in which case

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* Rankine. This is the best formula known by which to obtain the efficiency of the furnace.

—Actual Efficiency found. Boiler Power.—

$e = \frac{E'}{E} = 1\,\frac{53.6\left(=\frac{793}{14.84}\right)}{53.6+37.5} = .586$ for the actual efficiency and if we deduct 1/20 of this for the waste in unburnt fuel, unburned gases and smoke, waste by radiation, conduction etc, we have the ordinary efficiency of the locomotive furnace .557. Taking the total heat of steam, 1223.92 at 140 lbs pressure from the table page 55, and dividing the total heat of combustion of one pound of Cumberland coal, 13,363 found in Part II, by it, we find 10.92 lbs of water to be the theoretic evaporative power E, and the evaporative power that we should expect this boiler to exhibit under the usual pressure of 140 lbs, would be E' = 10.92 × .557 = 6.08 lbs of water per pound of coal.

Boiler Power, or its steam generating capacity, depends upon the Grate Area, the Extent of Heating Surface, the Draught, Quality of Fuel, Conducting power. Its available power also depends upon the application of the steam after it leaves the boiler. The horse power depends upon the amount of water it can convert into steam in a certain time, and this in turn is directly proportional to the amount of coal that can be burned in the same time on the grate. The maximum amount that this boiler can be expected to burn per hour is 125 (lbs per sq ft per hour) × 14.84 (Area of grate) = 1855 lbs. Now in the 16" × 24" cylinder there are 4825.4976 cubic inches or 2.792 cubic feet. If solid cylinders-full of steam are used these must each be filled and emptied twice in every revolution, and the cylinder capacity per revolution, or the amount of steam required will be 2.792 x 4 = 11.168 cubic feet. Suppose one of the conditions in the problem stated at the beginning of this part, to be a required speed of 25 miles per hour. (Above the average on the E.R.R. See Tables.) In one mile there are 5280 feet correspond-ing to 88 feet per minute so that the locomotive would have to move 88 x 25 miles = 2,200 feet per minute and dividing by the circumference of the driving wheel, 16.36 feet, there would have to be about 135 revolutions per minute. Hence 11.168 x 136 = 1507.68 cubic feet are used up and must be supplied per minute. The relative volume of steam at 140 lbs pressure is by the table page 55, 182.6 $\therefore \frac{1507.68}{182.6} = 8.26$ cubic feet of water to be evaporated per minute, equivalent to 8.26 x 62.4 (wht of a cubic foot) = 515 lbs, or 30,900 lbs per hour. As we have found, 1 lb of coal will evaporate 6.08 lbs. of water under these conditions and therefore $\frac{30,900}{6.08} = 5,082.$ lbs. of coal would have to be burned per hour. Now it will be seen by the Tables in Part V that the steam was usually cut off at 10" of the stroke. Therefore if only 10/24 ths = 5/12 of the steam is used the amount of coal burned would be less, or 5/12 of 5082 = <u>2118 lbs.</u>* which we see is rather more than this boiler can [consume.

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*Its maximum rate being 1855 lbs. per hour.

— The Feed Apparatus. —

With the Feed Apparatus, (III.) we leave the treatment of the Boiler proper and enter upon that of the numerous Boiler Attachments. These continue also through the two succeeding divisions. Mr. Forney, in mentioning the accidents liable to occur to locomotives, of which he enumerates nineteen of the most serious, estimates the order of their importance as 1°; Accidents caused to the locomotive as a whole, as in collisions of trains, running into an open draw, escape of an engine without any one on it, and running off the tracks; 2°, Accidents to the Boiler, such as its Explosion, bursting of a flue, or blowing out of a rivet; 3°, Failure of the Feed Apparatus; and 4°, Breaking of the mechanism, as the bursting of a cylinder, or cylinder head, breaking or bending a piston rod, connecting rod, crank pin, wheel, axle or spring, so that the right working of the Feed Apparatus is of much more importance than even that of the mechanism and second in importance only to that of the boiler itself. The Feed apparatus for the supply of water to the boiler consists of a single acting plunger pump and the injector. Sometimes the injector is dispensed with and then the rule seems to be that there should be two pumps each of which is of sufficient capacity to supply the boiler. In practice the apparatus used for the steady feed whether it be pump or injector is placed upon the right side of the engine, looking forward from the cab and from the specification we see that the pump occupies this side and is the one in constant use while running while the injector is only used at stations or in case the pump or its connections should fail. The general arrangement of the Pump feed is shown on Plate A, its details on Plate B. It consists of a plunger, 1 7/8" diameter, and working in a brass cylinder, its motion being derived directly from the crosshead, a set of pipes, cocks and three valves of similar construction called in reference to their position, the suction valve, pressure valve and check valve. On opening one of the cocks marked A, upon the tender in Plate E, the water flows along the horizontal pipe shown in the general view and enters the upright apparatus shown in Figs 34 & 33 at B. The two rounded vessels at either end of this act as air chambers, and between them the plunger, Fig 35, works back and forth in a horizontal direction. On the first stroke, the plunger enlarges the capacity of the pump and its connections by its own volume, tends to create a partial vacuum, and hence the water flows in and upward through the lower vessel, entering the pipe D, Fig 33, and compressing the air in the annular portion C, and passes upwards through the suction valve at E. The three valves all open upward by an amount of lift from $\frac{3}{16}$ to $\frac{1}{2}$* an inch, and are placed in brass cages which allow only the necessary amount of motion. On the return stroke, or stroke number two, of the pump plunger the suction valve closes, the water is forced through the pressure valve, F, by the mouth of the upper air chamber, G along the curved pipe, H shown in the general view, through the check valve I, shown in Plate A, and Plate B, Figs 29, 30 & 31, and into the boiler at a point just below the water level. The manner in which the pump is put together is clearly shown in the drawings, in Fig 34, the parts are held together by the bolts K and L, unscrewing which gives access to the suction and pressure valves, respectively. The pump at every point has an elastic medium

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*Forney.

against which to act, the energy exhibited in the velocity of the moving column of water on entering is taken up by the compression of the air in C, on the return stroke the direct pressure is equalized by the upper air chamber and at the check valve it has the elastic cushion of the steam in the boiler. Without these, we can hardly estimate the shock, or water hammer, which would be produced at each reversion of direction of the pump plunger, taking place as it does six times a second at ordinary speeds and sometimes ten or twelve times. It may be doubted, however, whether the recoil of the steam in the boiler and the springs which these air chambers constitute, has not a very violent effect upon the action of the pump at these high speeds. The supply of water fed to the boiler is regulated by a feed cock in the suction pipe. To ascertain whether the pump is working or not there is a small but very useful appliance which was invented by George Stephenson, called a 'Pet Cock', and placed in the lower part of the upper air chamber. This little affair when opened, lets out suddenly a stream of water on the inward stroke of the plunger, as its position would indicate, which indicates, when weak, that the pump is imperfectly working. It further shows which valve it is that leaks, or has become obstructed and when the pump is in perfect order it is sharp and well defined. In cold weather the pump and connections are prevented from freezing by pipes conducting steam from the boiler to the suction pipes, by which means the water is heated. If a locomotive supplied only with pumps should be snowed up, which sometimes occurs on the New England Roads, the engine would have to be jacked up so that the driving wheels could revolve without touching the rails, and the pump thus worked and the boiler supplied with water, but all this inconvenience and labor would be obviated if the boiler is fitted with that delicate instrument whose principle will be next explained, called

The Injector. Of the injector there are several different forms.* In their construction they are of four

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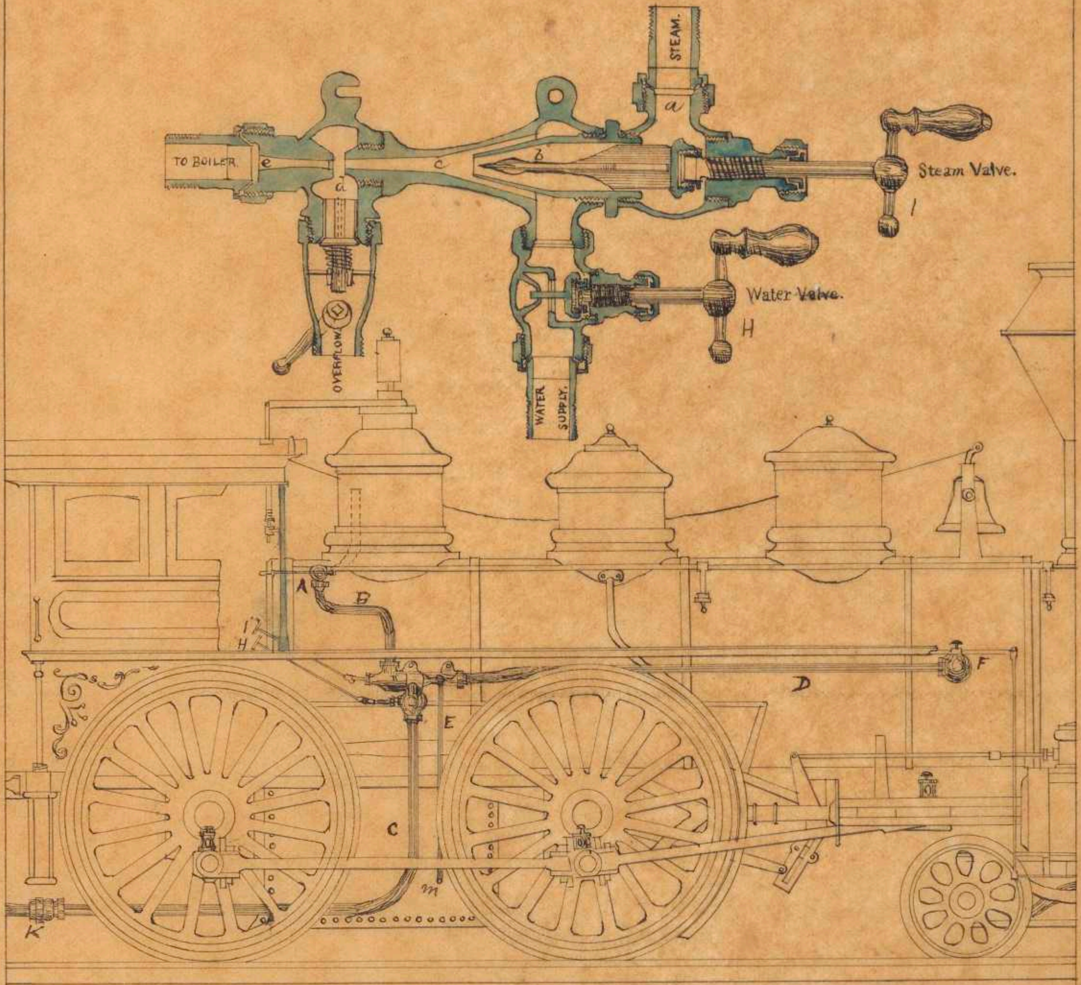
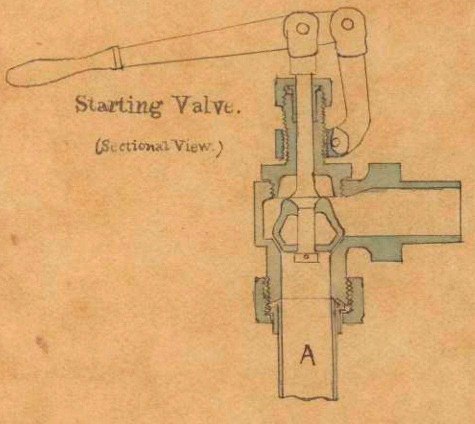
*The Rue's, Mack's, Seller's and Friedmann's Patents, besides the original Giffard, the elegantly illustrated catalogues of which are before me.

classes, the lifting, non lifting, self regulating or fixed. The original Giffard Injector has been in use in this country about fourteen years and with the improvements that have been made in it, is the form manufactured by Wm. Sellers. The form of injector with which this locomotive is supplied we see from the specification to be a number 6, Mack's, and to show its general arrangement of parts, position and principle I have made the very rough sketches inserted. The size or capacity of an injector is determined by the steam pressure and quantity of water evaporated per hour or the Horse Power of the boiler. As far as their working is concerned they may be placed in any position, upright, on their side or inverted. The non-lifting injectors are used mostly for stationary boilers, and where placed upon locomotives must be placed so low between the wheels that the water will run by its own gravity from the tender and fill the instrument. In the lifting class the water is drawn up through a suction pipe as in the pump. In the fixed nozzle injector the instrument works perfectly at but one pressure, that for which it is designed, and in the self-regulating it works easily at a great range in

MACK'S PATENT INJECTOR.

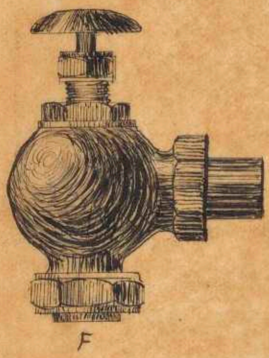




Starting Valve.

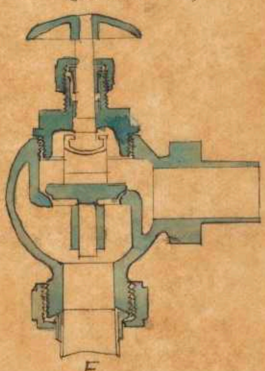
(Sectional View.)

Check Valve.



Check Valve.

(Sectional View.)



variation of pressure, but from the more delicate and complicated apparatus the fixed nozzle is often employed. The Mack's injector is of the fixed nozzle, lifting form, and has been exclusively used upon the engines of the Eastern Road since 1872. The diameter of the connections of the #6, is 1¼", it will lift water from 5 to 18'; at from 15 to 40 pounds pressure, and will deliver 870 gallons per hour or from 116 to 134 cubic feet of water at 120 pounds pressure. The rule by which they are ordered is, *assuming* the nominal horse power of the boiler to be the number of square feet of heating surface divided by 15 (for a multitubular boiler), each nominal horse power will require 7½ gallons of water per hour and the capacity needed is so determined. The position of this injector is horizontal, as shown in the middle figure, and Plate A, Fig 1, above the [illegible] board, and is either just above or below, in this case the former, the ~~foot~~ running board. Its parts consist of a starting valve A, the steam pipe B, conical *receiving*, *combining* and *delivery* tubes, shown respectively at b, c and e in the sectional view, the steam spindle I, water regulating handle H, water supply pipe C, overflow pipe E, sometimes a waste cock at K, the delivery pipe D and check valve F. It may be operated by opening the three valves A, H and I in various orders and its action may be described as follows;— To start the injector the steam valve, I, is first opened by which any condensed steam is blown out through the overflow which opens into the air at m, or within the cab. Then, 1st, the water valve, H, is opened which causes a stream of water to flow through the supply pipe, C, Plate A, through c and d, Fig 2, and out at the overflow. 2d, the steam valve* A is opened from one eighth to one fourth of a turn. By this means, dry steam from the dome enters the injector at a, passes by the feathers and through a minute opening in the steam spindle b, which is in what is called the receiving tube, since it receives the live steam from the boiler, passes into the combining tube c, where it is condensed by the water, and without losing its own velocity imparts an additional velocity to a portion of the water which it takes up, carries across the opening of the overflow d, into the delivery tube e, D, on the plate, and forces through the check valve, F, into the boiler. 3d, the steam spindle is next fully opened by which more and more of the water is taken up; and, 4th, if any remains flowing out through the overflow it is cut off

*Starting Valve.

by slowly turning off the water valve H. To stop it the steam valve A, the water valve H and ~~the and~~ the steam spindle I, are in succession turned off. Such in brief, is the action of this instrument in its simplest form. In the self-regulating form the combining tube c is movable and its distance from b regulated by a piston acted upon by the pressure of the over flow water. This piston by moving the tube c against the outside of b, cuts off the water supply; besides this it has an alarm check valve in the supply pipe which lifts if there is any failure of the valves to work. The principle of the injector is as follows;—It is that known as the "lateral action of fluids",* and was discovered by Venturi and Nicholson about seventy years ago. The velocity with which the steam enters the receiving tube at 120 pounds pressure is 1900 feet per second, as represented by the formula $v = \frac{Q\ (\text{Quantity in Cubic Feet})}{F\ (\text{Area of Cross section})}$, and on reaching the water in the combining tube its bulk and cross section, by its condensation, are reduced from 200 to 1500 times, say 1000. But its velocity or actual energy is not destroyed as it comes in contact with a thin ring of water, as would be the case if it encountered

*Roper's Handbook.

a large mass, and it is hence communicated to the water whose energy, proportional to its *weight* multiplied by the square of its velocity, drives it into the boiler against the steam pressure, with great momentum. It is equivalent to concentrating the original force due to the pressure of the steam upon a cross section of but $\frac{1}{1000}$ of its original area. The Injector is the most elegant of all the applications of science for practical use in the locomotive.

Connected with the subject of Boiler Feed is that of Feed water heaters into the discussion of which we cannot here enter. The utility of these arrangements lies either in the use of the waste heat of the furnace or of the enormous amount carried off by the exhaust steam. The difficulties which stand in the way of their use are that the former are expensive to keep in repair and complicated, and obstruct the course of the gases through the smoke box; and the latter tend to lessen the draught of the smoke stack. Although the Magoon heater* is simple in design and has been in use upon the 'Saxon' on the Boston and Maine Railroad, where it is said that it caused a saving of about three quarters of a ton of coal per day, for four months in

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*Scientific American – Sept. – 1875.

succession, and the apparent saving by its use is a matter of very easy calculation[*] yet I have the opinion of one[†] most interested in effecting such saving who says that all such contrivances, including the Proctor Spark arrester, upon the Lowell Road, are *not* as efficient as representations would seem to show and the fact that they are not universally used after having had a fair trial would seem to indicate that there is at present no real gain in economy by their use.

The Safety Apparatus, (IV) forms a large part of the Locomotive Boiler Fittings. They may be classed as of two kinds, those which insure the safety of the boiler directly and those which are added for the protection of the Engineer and his train, and the public. The first of these are the Steam Gauge, Water Gauges, Gauge cocks and lead plugs formerly used in the crown sheet of the fire-box, and the Safety Valves; the second includes the Air or Vacuum Brake, the steam dome and Whistle, the Bell, Head-light, Spark Arrester, Running Boards, Hand rails, Foot-board, Wheel Guards,

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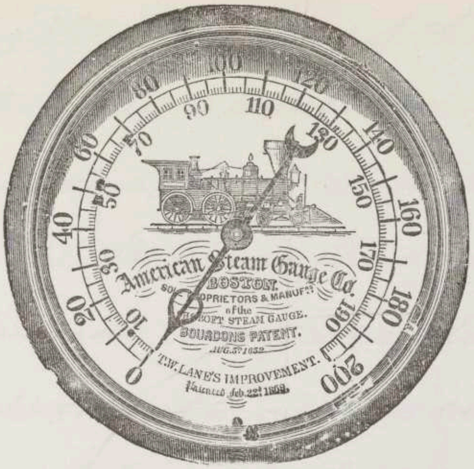
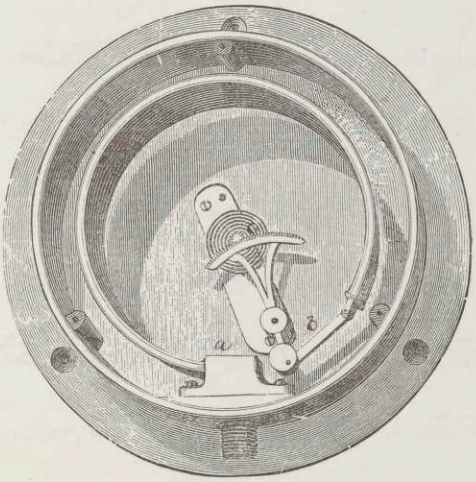
[*] Mr. J. B. Stanwood in his thesis "Locomotives", 1876, has discussed this subject and it seems needless to go over the same ground again.

[†] Mr Jno. Thompson – Master of Machy – E. R. R.

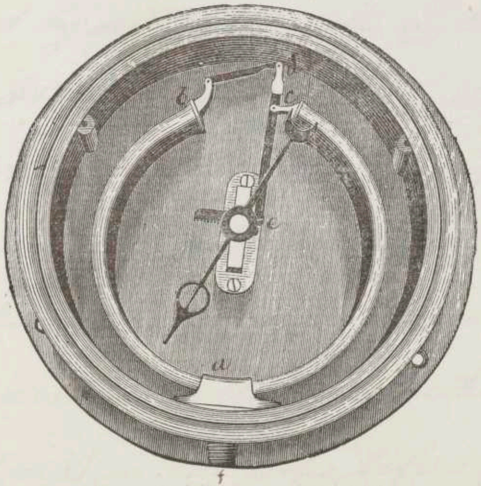
Cab, Pilot and Brooms of steel wire by which small obstructions are removed from the rails. The three first mentioned only, need further description, the others being indicated in Plate A of the Drawings, and in the Specification. The spark arrester in this locomotive consists in the wire netting stretched between cones placed base to base which forms the upper part of the smoke-stack. The office of these is, the first, by enlarging the cross-section of the pipe to diminish the velocity of the particles of coal, and the second or upper to deflect them downward again.

Of the Steam Gauge there are a number of different varieties, the Bourdon, Edson, Allen, Crosby, and Lane's Improved Bourdon. The principle upon which they all work are, in one class, the pressure of steam acting upon an elastic diaphragm in a similar manner to an Aneroid Barometer, or in the other, upon a curved tube of flattened cross-section. The Gauge with which this locomotive is supplied is the Bourdon form, having Lane's improvement, and manufactured by the American Steam Gauge Co. Boston. Both the original and its modified form is exhibited upon the following page.





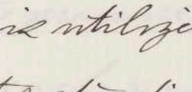
Bourdon Gauge.



Lane's Improvement.
(Inside View.)

—Construction of the Bourdon Gauge.—

As befitting the importance of this instrument to the locomotive boiler, a short description of its construction, from observations made during an afternoons visit to the American Steam Gauge Companies Works, may be made. The principle of the Bourdon Gauge was discovered in a rather curious way, by the observation being made that the coils of pipe in the worm of a still which was undergoing repairs, were enlarged and that the pipes tended to straighten when exposed to internal pressure. From this discovery the Bourdon Gauge was constructed and introduced into this country by Mr. E. H. Ashcroft, in 1851. As shown, it consists of a tube having an elliptic cross section bent into a circular form and attached by one extremity a, to the case, communication being made between its interior and the steam pressure through the pipe below. The other end, moving, turns the lever, b, which, by means of the toothed segment, at one end gears into a pinion c, and so gives motion to the hand. Although there was a bend, or U, in the pipe, before joining the gauge, for the purpose of collecting the condensed water, it was found that a detached portion of water would remain suspended midway between the extremities of the curved tube and often burst it, by freezing, or otherwise, cause inaccuracies in the indications. This is now obviated in the Lane's Improved form. The tube is held at the middle, a, one end, b, connected with the lever d e, which has a toothed segment turning a pinion on the spindle of the index as before. If the end b moved alone, c, would be the fulcrum of this lever, if c, alone moved, the lever would turn about d. As both ends, however, move apart together, when under internal pressure, the motion of the whole is utilized, as in the old form, ~~and~~ and much greater steadiness obtained. From the construction, any water in the tube would run out, and in practice the ends of the tube contain compressed air. The curved tube is originally straight and round, 5/8" outside diameter, and made of a hard composition. By repeated drawings through dies its elliptic cross section is produced, of the following dimensions.



The tube is hardened by this drawing process. The tube is then bent into circular form, after filling its interior with sand, and tested to 150 or 160 lbs.

The Gauge is graduated by the mercury column, 2·04* inches in height of which, equivalent to 27·67" of water, produces 1 pound pressure. It is screwed upon an iron pipe, on which is also a Standard Test Gauge, connected with a pump which pumps water, producing the required pressure. On the right is the mercury column in a glass tube ½" diameter, the lower end of which is at the bottom of a box nearly full of mercury at the ordinary pressures. The water from the pump presses upon the surface of this mercury which rises in the tube and indicates the height of mercury necessary to balance the pressure, by a scale of inches placed behind it. At each pound of pressure a mark is made upon the gauge opposite the end of the index. On the left is an iron pipe which runs from the bottom to top of the building, in length 46 feet, which contains a column of mercury and is used for pressures above 35 pounds. On the surface of the mercury in the tube is an iron float suspended by a cord which passes over a pulley, nicely balanced and 6 inches in diameter, placed at the top of the building. It thence runs down beside the tube in a box a section of which can be opened. Against the

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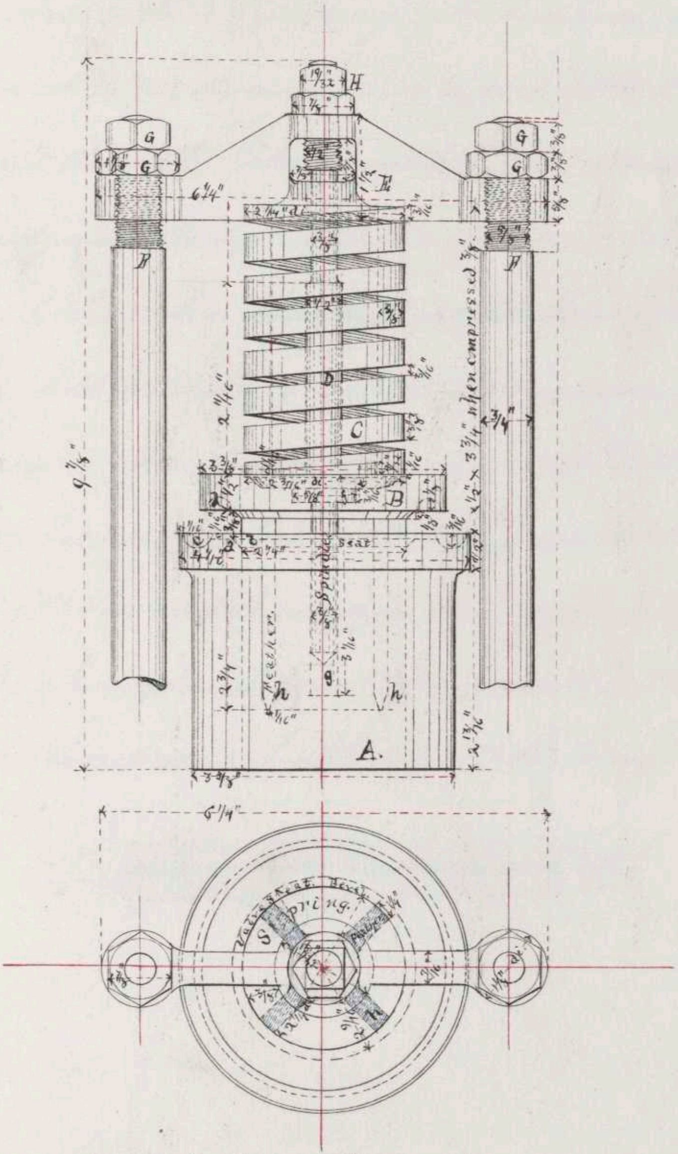
*Corect at 70° F.

cord is a scale of inches and on it a small weighted clamp, the top of which shows the reading on a scale:- It can be set at any point by the mercury column in the glass tube at the time of the experiment thus preventing the contraction and expansion of the cord from producing errors in the result. The divisions upon the gauge are then carefully cut, the lettering stamped and filled with black wax or asphaltum, the brass silvered with chloride of silver and the Gauge completed.

The cause of the tendency of the bent tube to straighten is the same as that acting upon the boiler shell. Pressure tends to round out the flat sides till the tube becomes circular and of its original 5/8" diameter. As it approximates to this, its outer side would have to be lengthened and inner side compressed to preserve the same radius of curvature, and hence its radius increases, as it straightens, and throws the ends apart.

A Safety Valve consists of a disk which closes the outlet of a short pipe leading from the boiler. Of these, the locomotive boiler is fitted with two, each 2 1/4" in diameter, of precisely similar construction and of the Richardson form, and which is illustrated by the folling figure:-

Plate VI.



Richardson's

'Pop'

Safety Valve

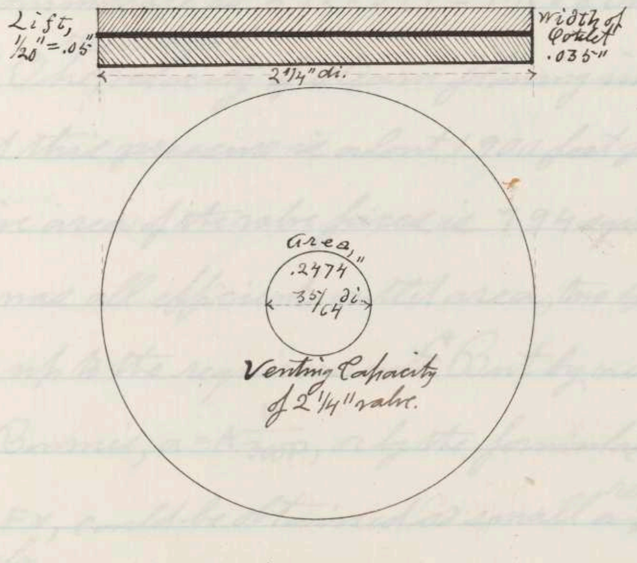
for

Locomotives.

Scale, 3/8" = 1'.

F. E. Galloupe.

The valve B, of brass, which has a conical face, 1/8" in depth, and feathers h, fits upon its seat in the brass cylinder A. It is held down by the steel spring C, which is here represented as compressed 3/8"; by the cross piece E, and bolts F F which are fixed into the boiler. The spindle, D, with the screw bolt H, serves to adjust the lift of the valve. In order to be equal to the area of the valve this lift would have to be, $\frac{\pi d^2}{4} = 2\pi r \times h$, or $h = d/4$, but actually, from the increasing force necessary to compress the spring by equal amounts, the greatest lift of the valve may be taken at 1/20th of an inch. As the coning is 45°, the real opening is but 7/10 of this or $.05 \times .7 = .035$". To show plainly what this amount is, the figure below has been drawn full size. The area thus opened



for the passage of the steam is but. $2\pi r \times .035 = .2474$ sq. inches, corresponding to a pipe a trifle over ½" in diameter. Prof. Burg of Vienna found, from actual measurements.

that at only 12 lbs pressure the rise was but $\frac{1}{36}$", and that it rapidly decreased, with increase of pressure, till at 90 lbs, the opening was but $\frac{1}{168}$". With the rise of $\frac{1}{20}$" the pressure necessary to keep the valve open increases at least 5 lbs. The safety valves should each be sufficient to discharge all the steam that the boiler is capable of generating,— that is, to be of sufficient capacity to discharge the steam as rapidly as it can be formed. At 140 lbs pressure, we have found that the coal capable of being burned per hour is 1855 lbs or 0.517 lbs per second. The corresponding evaporation per second would be .517×6.08 = 3.143 lbs of water. The relative volume of steam at this pressure is 182.6, or 182.6 × .016 (volume of 1 lb of water) = 2.92 cubic feet for each pound of water evaporated. Hence the maximum volume of steam which the two safety valves should accommodate is 2.92 × 3.14 = 9.1688 cubic feet per second. The theoretical velocity of steam flowing into the atmosphere, at this pressure is about 1900 feet per second. The collective area of the valve faces is 7.94 square inches and if this was all efficient outlet area, two of these valves would come up to the requirements.* But by neither of Rankine's rules, Bourne's, $a = A\frac{V}{300P}$, or by the formula of efflux, $v = \sqrt{2gh}$, $Q = Fv$, could be obtained so small a required area. It seems to be only the constant attendance upon locomotive engines and the watching of the Steam Gauge, that prevents the generation of steam faster than delivered by the valve, and the consequent over-pressure.

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*Stated to be so by Roper.

—The Transmission Apparatus—Steam and Exhaust Pipes.—

The Transmission Apparatus (V), or that by which the power in the steam is transmitted to the engine, consists in the Throttle Valve, the Steam Pipe, the Dry-pipe, in the boiler, and its Branches; and that by which the steam escapes into the atmosphere after doing its work in the cylinder, or the Exhaust Pipes and Blast Orifice. The construction of the former is shown in Figs 12–15 Plate B, of the Drawings, and in Figs. 90 and 91 Plate C. As the boiler pressure is usually reduced from its pressure of 140 lbs, 20 lbs. by this apparatus, its efficiency may be represented as $\frac{140-20}{140} = .\underline{857}$, and this is caused by, and varies as the density of the steam, the square of the piston speed, and of the ratio of the area of the piston to the cross section of the steam pipe, and as the bends and friction in the pipes, which vary directly as the density and square of the velocity of the steam, and inversely as the diameter of the pipe. The motion of steam or its efflux into a fluid of less density, or the atmosphere depends upon the difference of pressure. The effective pressure, or that above the atmospheric, only, acts to produce the motion of steam through the steam pipe and its efflux into the cylinder. In doing this it can do work represented by $V.w \times h$, where V is the volume of the steam in cubic feet, w, the

— Efflux of Steam into the Cylinder, —

weight of a cubic foot, and h, the distance through which it moves which may always be considered as a height through which the weight, V w, falls. If there was no resistance to the motion, from the bends in the pipe, in falling through the height, h, from a state of rest, the weight of steam, $W = V \cdot w$ would acquire a theoretic velocity, v, and the energy thus stored in it would be represented as on page §..., by $\frac{1}{2} \cdot M \cdot v^2 = \frac{1}{2} \cdot \frac{W}{g} \cdot v^2$, and since there is no loss, these quantities must be equal, or $\frac{1}{2} \cdot \frac{Vw}{g} \cdot v^2 = V \cdot w \cdot h$, $h = \frac{v^2}{2g}$, $v = \sqrt{2gh}$.* From this extremely simple formula the efflux of steam is found, for the quantity, h, is the height of a column of steam, one inch square equivalent in weight to the pressure of the steam per square inch above the atmosphere, or $\frac{p}{w} \times 144''$† Hence to find the velocity with which steam of 100 lbs. would escape into the atmosphere, we apply the formula $v = C \times 8.025 \sqrt{\frac{p}{w} \times 144}$. The pressure per square foot would be, more exactly $100.304 \times 144 = 14,443.776$ lbs. The weight of a cubic foot of steam at this pressure being .26405‡, the velocity would be, $v = C \times \sqrt{2g} \times \sqrt{\frac{14,443.78}{.26405}} = C \times 8.025 \times 240.21 = C \times 1928$ feet per second. The coefficient, C, of efflux, is given by the Scientific American at .62 for this pressure and for a mouthpiece of the form of the contracted vein. Hence the velocity with which it could flow into the cylinder when

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*The formula is thus proved by Weisbach. † D. K. Clark. ‡ Porter.

§ Omitted.

their is no back pressure would be $v = .62 \times 1928$* = 1195 feet per second. This velocity increases slowly with the pressure and calculation shows how ample this immense velocity is, in the branch pipe 4½" diameter, to keep up with any piston speed that can be produced in the locomotive. The resistances must be very great to reduce its velocity so that its pressure falls in the proportion stated. Probably the greater portion lies in the valve chest and steam passages and from the wire-drawing of the steam by the valve.

The Engine. We have now ascertained the mode of action and examined the theory in one or two points of the Locomotive Boiler, ~~either ignoring or~~ barely touching upon others of equal importance. The consideration of the details of the mechanism lies before us. The remaining figures in the Drawings, Plates A, B, C and D, contain full details of, it is believed, every important part of this. It is necessary to omit the discussion of the details of the engine, for our subject has already expanded beyond the limits proper for a thesis. It is with real regret that this is found expedient, for the facts and principles relating to them have been collected and studied during a considerable

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* Roper gives it 1876 ft, and D. K. Clark 1951.

period of time, and the material already at hand would swell the volume of this paper to a considerable extent. For this reason it is thought advisable to omit the whole, merely mentioning the topics which may be considered to complete the subject, and which are as follows;— In the *Cylinder*, I, its position, and its Construction,—its heads, piston, packing, casing, valve face, steam chest, steam and exhaust passages—would be followed by a discussion of the reasons for its particular dimensions—what has determined its proportion and its relation to other parts, to the boiler, its power, the tractive power, and to the steam expended in it. And the friction in it, and methods by which it is diminished by lubrication.

II, Following, would come the description, office, and geometrical construction of the *Valve Gear*, the Slide Valve, Rods, Rocker, Link, hangers, the Eccentrics, their disks, straps and rods, and the Reverse Apparatus, the quadrant, the reverse lever, rod, lifting links and counterbalance springs. Then, much might be said upon the action of the valve, the effect of lap and lead as determining the quantity, and time of admitting, steam to the cylinder, and how these are affected by the construction of the link and connections. And the exhibition of the valve movements by motion curves.

In the Action of Steam in the Cylinder, III, the mode of treatment intended was the discussion of actual steam indicator diagrams, by which their differences from the assumed theoretic diagram, and the actual condition of the steam in the cylinder, could be found, — its pressure, mean pressure, real point of cutoff as distinguished from its apparent, the curve of its expansion, release, compression, and the subject of condensation. Some splendid indicator cards have but just been received,* from two engines built by the Northern (N. H.) Railroad, but too late for discussion here. The Action and Theory of Blast pressure would have to be considered, here, in connection with the cylinder.

The Transmission of Power to the Wheels, IV, relates to parts such as the piston, cross-head, connecting rod and crank. The efficiency of the Crank as a means of converting reciprocating into circular or rotary motion. The effect of the angularity of the connecting rod over that pro-

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* From J. A. Lauder, Master Mechanic of the Road. They were taken last summer, and exhibit a remarkably perfect steam line, and very little back-pressure.

duced if there was harmonic motion. The weight of reciprocating parts, their accelerations and retardations at the dead points and the efficiency of the combination.

The Running Gear, V, includes the wheels, shafts, journals and framing to which they are attached. The locomotive would here be regarded as a carriage, or vehicle for the boiler and mechanism. The action of centrifugal force which is partially counteracted by the tractive pull, upon curves.

In the Balancing of the Engine, VI, would be considered the means for preventing the zigzag or lateral tendency of the motion, to cause the flanges of the wheels to grind against the rails, arising from the alternate maximum force of the pressure upon the pistons upon each side of the engine, and how this is affected by the gauge of the road. And of balancing the weight of the reciprocating parts in the driving wheels. All these relate to the engine alone and doubtless other points would suggest themselves in the treatment of them. The Tractive Power and Train Resistance will be remarked upon in Part IV.

Part IV.

Trial of an American Passenger Locomotive.

By the kindness of Mr. Jno. Thompson, "Master of Machinery" of the Eastern Railroad Company, the opportunity was had of riding upon the engines of two of the fastest passenger trains on that road, and of taking therefrom data concerning the actual running of locomotives. The trains selected were the 2.15 P. M. Rockport Train from Boston which runs for a distance of 36 miles, and after a stop of 55 minutes at the terminus makes a return trip to Boston; and the 8.30 A. M. Bangor Express train from Boston, which is also a Pullman train, and the fastest on the road, with the exception of the night Pullman, and which runs to Portsmouth, 56 miles from Boston with the same engine which is there detached and 18 minutes after, makes a return trip to Boston. After obtaining information concerning the running of these engines at Prison Point, on Tuesday afternoon, March 14th, armed with my pass, engine No 36, "The John Howe," was taken, to enjoy the novel sensation of

A Ride upon a Locomotive. My watch was set very carefully by Boston time; a table made out with blank columns for data; pencil sharpened, the driving wheels and pump plunger measured, the depth of water in the tender taken, an estimate of the amount of coal aboard and the capacity of the tank obtained; the make of the engine*, the weather, condition of the rails, direction of the wind, the steam gauge, the numbers of the cut off notches on the reverse quadrant and the number of cars noted; and we started. It was exhilarating, though the excitement caused fatigue. As we passed through tunnels, over bridges and crossings, and curves, upon embankments where our safety, and that of the train behind us, depended upon each individual rail not yielding, it became intense. Upon the three succeeding days trips were made to Portsmouth and return upon engine No 55, which was built at the Hinkley Works in October, 1875, and is the engine the details of which have been given

*Mason Locomotive Works – Taunton.

and parts discussed in Part III. We passed the level exposed marshes at Lynn, through the Salem and Newburyport tunnels, by the Silver mine and over the long bridge over the Merrimac, at the latter place, and rapidly diminished the distance to our destination, passing in succession through Salisbury, Hampton and Greenland. The faster we went the more coal the fireman threw in. No accidents occurred on the trips and the most important incidents were the catching of the mail bags, a bent draw-pin at Portsmouth and a race with a train up on the Maine Road into Somerville. Mounted upon the firemans seat, the engine rode much easier than was expected and except at the maximum speed little difficulty was experienced in writing. The time was accurately taken at which the engine passed each station, the steam pressure, cut-off notch and the amount of coal thrown into the fire-box. In brief, the aim was to jot down every occurrence that took place in regard to the engine. The following are the data taken and the results obtained.

Table V.
Wednesday, – Mar 16th,
Down Trip.

Miles from Boston.
2.
3
5
6
10
11
12
16
18
20
22
27
1

Data and Results from the Hinkley Engine No. 55, Eastern R.R. – Down Trip – 8.30 A.M. Bangor Train.

Date, Wednesday, Mar. 15th, 1876.

Day, dry, chilly, ther. 15°–40° F., Wind, W. and very strong.

TABLE V.

At Boston

{Coal in Tender at starting, 15 tubs @ 400 lbs. = 6000 lbs.
Depth of Water in Tender at starting, about 42"
Number of Cars, 5 Pass., 1 Pullman, 1 Baggage, 1 Postal, Total 8.

Miles from Bos'ton.	Train due. Time.		Station.	Train Arrival and leaving. Corrected Time by Watch.			Steam Pressure Gauge Readings. lbs.	Coal Record.			Cut off Notch. Approx. inches of Stroke.	Speed.				Water & Steam Record.		Notes. Oiling, Shutting Off, Braking, Speed, Raking Fire, Air Brake Pressure, etc.
	H.	M.	leave	H	M	S		Weight fired between Stations lbs.	Aggregate Weight. lbs.	Pounds of Coal per mile run.		Revs. per Minute.	Feet per Minute.	Max. Rate. Miles per Hour.	Average Rate. Miles per Hour.	Cubic Feet of Water Evaporated between Stations.	Weight of Water & Steam consumed per Mile. lbs.	
	A.	M.																Watch practically correct with
	8	30	Boston.	8	30	34	137	13.5	13.5							2.079		Railroad Time at 8.30 A.M.
				arr.	33	15						–	–	–				
			Prison Point.	8	33	20		81.	94.5		14"					12.474		Stopped 5 seconds.
															15.1		454.1	
			B. & M. R.R. Crossing.	8	35	40	138	-----	------		21 1/8							
												–	–	–				
2.			Somerville.	8	37	5		27.	121.5		20 1/2					4.158		
											19							
			Curve at Somerville.	8	38	30		67.5	189.	61.	17				26.6	10.395	907.9	
											14							
3			Everett.	8	40	45	124	40.5	229.5	68	10					6.237		Took 50 secs. to stop after brake
				arr.	43	50						---	---	---	38.7		194.6	was put on.
5	8	42	Chelsea.	8	44	15	139	101.3	330.8	20	10					15.600		Stopped 25 secs.
															14.1		973.4	Oiled cylinders from Cab.
6			Revere.	8	48	30	130	67.5	398.3	101						10.395		
			Oak Island.	8	51	50	115	141.8	540.1		10				32.4	21.837	502.8	Air Brake Gauge, 100 lbs.
10			West Lynn.	8	55	55†	114	13.5	553.6	53						2.079		
				arr.	57	20†						---	---	---	42.3†		129.7	Engine Clock 50 secs slow by watch.
11	8	59	Lynn.	9	0	30	134	135.	688.6	14	10					20.790		Stopped 3 minutes, 10 secs.
															16.7		1297.3	
12			Swampscott.	9	4	5	123½	94.5	783.1	135						14.553		Throttle one half open.
				arr.	10	50	126								35.6		227.0	Oiled Cylinders.
16	9	12	Salem.	9	13	15	133	81.	864.1	27						12.474		Stopped 2 min 25 secs.
			Know-nothing.	9	15	10						----	----	----	17.1		389.2	
				arr.	20	15	118											
18	9	20	Beverly.	9	20	50	127	148.5	1012.6	41	10					62.869		Stopped 35 secs.
			(9.24) Added 5 sec.	arr.	27	45						150†	2454	27.9	17.3		1961.5	†Steam pressure 125 lbs. Very heavy up-grade – 43' to the mile.
20	9	26	*North Beverly.	9	28	5	130	94.5	1107.1	74	14					14.553		Oiled Cylinders.
				arr.	32	45					10–	160†	2618	29.8	25.1		453.5	†Steam pressure 123 lbs.
22	9	32	Wenham.	9	33	25	123	216.	1323.1	48						33.264		At 9.32 reverse lever was put full forward, 10 secs. later the brake was put on, and full stop was made at 9–32–45.
				arr.					Total for 27 miles		10–	192†	3141	35.7			415.2	†Steam Pressure 123 lbs.
27	9	43	Ipswich.	----	----	----				43								Took on water.
									Average lbs. per mile, Coal.	57		Average lbs. of water consumed per mile, 658.9						
1	2		3		4		5	6	7	8	9	10	11	12	13	14	15	16 – Column.

*Flag Station. † Time doubtful.

Table V - continued

Da

Miles from Boston.	Train due Time H	M	
	A.M. leave		
27	9	43	
30	9	50	
34			
37	10	05	
39			
42	10	20	*
43	10	25	
46	10	33	ile.
49	10	40	
51	10	47	*m ing.
56.	10	57	ap O " * "
1	2		

Data from the Hinkley Engine No 55, E.R.R. on the 8.30 A.M. Bangor train from Boston.

Date, Wed, Mar 15th 1876.

TABLE V - Continued.
Down Trip.

Ipswich. { Depth water in tender, before filling, 16".
" " " " after " 41½".

Miles from Boston.	Train due Time		Station.	Train arrival and leaving Corrected Time by Watch			Steam Pressure	Coal Record			Cut off	Speed				Water & Steam Record		Notes.
	H	M	leave	H	M	S	Gauge Reading lbs.	Wht. of Coal fired between Stations lbs.	Aggregate Weight lbs.	Pounds of Coal per Mile run.	Notch. Approx. in. of Stroke	Revs. per Minute.	Feet per Minute.	Max. Rate Miles per Hour.	Average Rate. Miles per Hour.	Cubic Feet of Water Evaporated between Stations.	Weight of Water or Steam consumed per Mile lbs.	Oiling, Shutting off, Braking, Speed, Raking fire, Air brake Pressure.
	A.M. leave						122		1323.1									Took water.
27	9	43	Ipswich.	9	46	25	137½	94.5	1417.6		10				21.6	5.387	112.1	Safety valve blowing. Throttle ½ open.
											10	240	3927	44.6				
30	9	50	* Rowley.	9	54	45	114	128.3	1545.9	32.	10	(11 4)			27.7	7.313		
											10	150 (11 0)	3454	27.9			114.1	At bridge.
34			* Knight's Crossing.	10	3	25		162.0	1707.9	32.	10				16.9	9.234		
			Know-nothing.	10	12	20											192.1	
37	10	05	Newburyport.	10	14	0	143	121.5	1829.4	54.					22.5	6.926		Valve blowing.
											10	192	3141	35.7				Oiled cylinders
39			* Salisbury.								10	(12 4)						
																	86.4	
42	10	20	* Seabrook.	10	25	5	132	81.0	1910.4	24.	10				14.1	4.617		
																	288.1	
43	10	25	* Hampton Falls.	10	29	20	136	175.5	2085.9	81.					24.5	10.004		
																	208.1	
46	10	33	Hampton.	10	36	40	120	216.0	2301.9	59.					24.8	12.312		
																	256.1	Very heavy up-grade, 43 ft to a mile.
49	10	40	North Hampton.	10	43	55	110	189.0	2490.9	72.	14					10.773		
											14	140 (10 2)	2290	26.	17.1		336.1	Heavy up-grade.
51	10	47	* Greenland.	10	50	55	120	243.0	2733.9 Total for 56 miles run.	95.	10					13.851		Pressure in air brake fell from 76 lbs to 40 lbs in stopping the train, with the brake pumping.
											10	200 (11 1)	3273	37.2				
											10	220 (11 1)	3,600	40.9	29.8		172.8	Raked fire six times after leaving Boston.
56.	10	57	arrive at Portsmouth.	11	1	0	125			49.	10					Average lbs. of Water consumed per mile for 29 miles	196.2	
			* Flag Stations			Average steam pressure for 56 miles	127.	Average lbs per mile, 55. " for 56 miles " " 56.										
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 - Column.

Portsmouth, { Depth water in tender, before filling, 31¼"
" " " ", after ", 40¼"

Da
Da
Da

Miles from Boston.
2
2
3
5
6
10
11
12
16
18
20
22
27
1

Table VI.
Thursday, Mar 16th,
Down Trip.

Data from Hinkley Engine No. 55, E.R.R.—Down Trip—8.30 A.M. Bangor Train.
Date, Thurs. Mar 16th, 1876.
Day, dry, pleasant, ther. 40° F, Wind W, breeze.

TABLE VI.

Boston { Coal in tender at starting, 14 tubs --- = 5,600 lbs.
Depth water in " " , about 40".
Number of cars, 8, same as on Wednesday.

Miles from Boston.	Train due Time.		Station.	—Train arrival and leaving— Corrected Time by Watch.			Steam Pressure Gauge readings.	— Coal Record. —			Cut off Notch. Approx. inches Stroke.	— Speed. —				Water & Steam Record.		Notes.
	H	M	leave	H	M	S	lbs.	Wht. of Coal fired between Stations lbs.	Aggregate Weight. lbs.	Pounds of Coal per Mile run.		Revs. per Minute.	Feet per Minute.	Max. rate. Miles per Hour.	Average rate. Miles per Hour.	Cubic Feet of Water Evaporated between Stations	Weight of Water or Steam Consumed per Mile. lbs.	Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc.
	A.	M.																
	8	30	Boston.	8	31	0	132	0.	0.		10"							Watch practically correct at 8.30. Oiled cylinders.
			Prison Point.	8	33	40	131	40.5	40.5		21⅛					6.845		
															17.8		213.5	
			B.&M. Crossing.	8	36	15	130	0.	40.5		10							
2			Somerville.	8	37	45	123	27.	67.5			......	......	......		4.563		
2			Curve at Somer.	8	39	0	122	81.	148.5	34.					17.1	13.689	1138.9	
3			Everett.	8	41	15	119	40.5	189.	81.	10					6.845		
											10–	200	3273	37.2				
											21⅛–	180 (11	826) 2945	33.5	36.7		213.5	Raked fire.
5	8	42	Chelsea.	8	44	30	132	94.5	283.5	20.	10	(12	7)			15.971		
											10	160	2618	29.8×			996.6	×Taken at 47m 25 secs & counted till 48-55.
															13.6			
6			Revere.	8	48	55	127	94.5	378.	95.	10					15.971		
											10–	200	3273	37.2×				×At 51m 0 secs.
			Oak Island.	8	51	50	126	81.	459.		10	220 (12	3600 726)	40.9×	32.7	13.689	462.7	× " 54".
											10–							×At curve, 54m 45 secs.
											----–	120 (12	1963 826)	24.1×				
10			West Lynn.	8	56	15	128	0.	459.	44.								
					58	25	138×				14				27.7		-------	×Valve blowing off.
11	8	59	Lynn.	9	00	0	139	47.3	506.3	0.	10					7.994		Raked fire. Damper open in fire box door.
											10–	160	2618	29.8	16.0		498.8	
12			Swampscott. (9.09)←	9	3	45	128	94.5	600.8	47	10					15.971		
					10	15	134				10–	220 (12	3600 726)	40.9+				+Time, at 9-6m Oiled cyls.
											6–	240 (12	3927 5)	44.6+	36.7		249.0	+ " " 7m 15 secs.
16	9	12	Salem.	9	13	0	133×	67.5	668.3	27						11.408		×Valve stopped blowing off.
					15	50	135				21							
			Know-nothing.	9	16	15	136				14				15.8		355.9	
					20	35	138×				10–	140 (12	2290 822)	26.0+				+Time, 18m. Raked fire.
18	9	20	Beverly.	9	21	15	136×	67.5	735.8	34.	10	160	2618 (133)	29.8+		11.408		×Valve blowing.
											10–	150	2454 (132)	27.9+				+Heavy up-grade, time, 23m,
											-----	--80		+	18.0		355.9	+Time, 24m 20 secs.
20	9	26	*North Beverly.	9	27	55	134	54.	789.8	34	10		1309 (129)	14.9		9.126		+ " 26 ".
											10–	180	2945	33.5+	22.8		284.7	+Grade, Steam 126 lbs, time 30m. Raked fire.
22	9	32	Wenham.	9	33	10	137×	136.	924.8	27.	6–	200	3273	37.2+		22.815		×Valve blowing. Raked fire.
											6–	260	4255	48.4+				+Level, Steam 128 lbs, time, 37m.
											6–	230	3764	42.8+	31.6		284.7	+Steam, 128 lbs, time, 38m.
27	9	43	Ipswich Cor.	9	42	40			Total for 27 miles.	27.	6							+Steam, 124 ", " 41m. --Maximum speed attained on trip.
									Average lbs per mile,	47			Average lbs. of Water per mile, for 27 miles,				--- 421.2	
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16—Column.

*Flag Station.

Table VI continued.

Dov
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Da

Miles from Boston
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46
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51
56
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Data from Hinkley Engine No 55; E. R. R. – Down Trip. – 8.30 A.M. Bangor Train.
Date, Thurs, Mar 16, ~~th~~, 1876.
Day, dry, pleasant, Wind; E (veered to E at 9.40 AM)

TABLE VI – Continued.

At Ipswich { Depth water in tender before filling, 20".
" " " " after " , 42¾"

Miles from Boston	Train due Time		Station.	Train arrival and leaving – Corrected Time by Watch			Steam Pressure. Gauge readings.	– Coal Record –			Cut" off Notch Approx. index of Stroke	– Speed. –				Water & Steam Record.		Notes.
	H	M	leave	H	M	S	lbs.	Wht. of Coal fired between Stations lbs.	Aggregate Weight. lbs.	Pounds of Coal per Mile run.		Revs. per Minute.	Feet per Minute	Max rate Miles per Hour.	Average rate. Miles per Hour.	Cubic Feet of Water Evaporated between Stations.	Weight of Water or Steam Consumed per Mile. lbs.	Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc.
	A.	M.							924.8									
27	9	43	Ipswich.	9	46	5	135	162.	1086.8		10" –	240+	3927	44.6		20.088		Raked fire. + Time 9.49, pressure 123 lbs.
											10 –	240+	3927	44.6	25.3		417.8	+ " 50m " 120 lbs.
30	9	50	*Rowley.	9	53	10	130	121.5	1208.3	54.	10					15.066		Raked Fire.
											10 –	140+	2290	26.0				+ Time, 55m, Gauge, 128 lbs.
											10 –	190+	3108	36.3	36.0		235.1	+ " 56m, " , 126 " Up Grade.
											10 –	204+	3338.	37.9				+ " 58 " ; " , 124 ".
34			*Knights Crossing	9	59	50	120	54.	1262.3	30.	10					6.696		
											10 –	220+	3600	40.9				+ Time, 10-1m, Gauge, 119 lbs.
			Know-nothing.	10	3	10	133	67.5	1329.8		10				17.8	8.370	313.2	Oiled Cylinders. At Newberryport, – depth water
37	10	05	Newberryport.	10	9	55	141	54.	1383.8	41.	14					6.696		in tender, 3 feet.
											10	200+	3273	37.2	25.7		208.9	+ Time, 13m, Gauge 126 lbs. At Bridge.
39			*Salisbury.	10	14	35	124	135.	1518.8	27.	10					16.740		Raked fire.
											10 –	190+	3108	35.3				+ Time, 16m, Gauge 121 lbs.
															28.3		348.2	
											10 –	180+	2945	33.5				+ Time, 18m, Gauge, 124 lbs. Up Grade.
42	10	20	*Seabrook.	10	20	55	133	40.5	1559.3	45.	10					5.022		Raked fire.
											10 –	160+	2618	29.8	14.4		313.4	+ Time 23m, Gauge, 122 lbs.
43	10	25	*Hampton Falls.	10	25	5×	122	67.5	1626.8	41.						8.370		No stop made.
											10 –	120+	1963	24.1	33.6		174.1	+ Time, 27m, Gauge 117 lbs. Very heavy up-grade.
					30	25	135×											
46	10	33	Hampton.	10	33	10	138	27.	1653.8	23.	14					3.348		×Valve Began to blow off at 144½ while at station.
												----	----	----	24.8		69.6	Raked fire.
49	10	40	North Hampton.	10	40	25	138	40.5	1694.3	9.	10					5.022		Raked fire. Stopped 1 minute, –
											10 –	156+	2552	29.0	16.9		156.7	+ Time, 42m 30 secs, Gauge 138 lbs. Raked fire. Up grade.
51	10	47	*Greenland.	10	47	30	----	229.5	1923.8	20.	10					28.458		Stopped 20 seconds. Raked.
									Total for 56 miles.		10 –	160+	2618	29.8				+ Time, 49m, Gauge, 120 lbs.
											10 –	220+	3600	40.9	29.3		355.1	+ " , 50 ", " , 118 lbs.
											10 –	240+	3927	44.6				+ " , 52 ", " 110 lbs. Up-grade.
56	10	57	Portsmouth. Arr.	10	57	45	118			46.					Average lbs. of water per mile, for 29 miles. –		259.2	Took 40 secs to stop from full speed.

Average Steam Pressure for 56 miles, 131 lbs.
Average lbs per mile, 34.
" lbs for 56 miles, 41.

At Portsmouth { Depth water in tender before filling, 27".
" " " " after " , 42"

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 – Column.

*Flag Stations.

At Portsmouth
Estimated coal in tender 6½ tubs.
Coal taken aboard, 2 tubs. = 800 lbs.

Table VII.
Friday, Mar 17th,
Down Trip.

Data from
Date, Frid
Day, Wet, S

Miles from Boston.	Train due. Time H	M
	A.	M
	8	3
2		
2		
3		
5		
6		
10		
11		
12		
16		
18		
20		
22		
27		
1		

Data from Hinkley Engine No 55; E.R.R. – Down Trip, – 8.30 A.M. Bangor Train.
Date, Friday, Mar 17th, – 1876.
Day, Wet, Sleety, icy, slippery, Wind E.

TABLE VII.

At Boston { Coal in tender at starting, estimated 15 ins. Tender full = 6000 lbs.
Depth water in " " ", 41".
Number of cars, 8; same as on Wednesday.

Miles from Boston.	Train due. Time. H	Train due. Time. M	Station. leave	Train arrival and leaving Corrected Time by Watch. H	M	S	Steam Pressure Gauge readings lbs.	Coal Record. Wht. of coal fired between Stations lbs.	Coal Record. Aggregate Weight. lbs.	Coal Record. Pounds of coal per Mile run.	Cut off Notch. Approx inches stroke	Speed. Revs. per Minute	Speed. Feet per Minute.	Speed. Max. rate. Miles per Hour.	Speed. Average rate Miles per Hour.	Water & Steam Record. Cubic Feet of Water Evaporated between Stations.	Water & Steam Record. Weight of Water or Steam consumed per Mile. lbs.	Notes. Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc.
	A.	M	(8.28) 10" add. ←	A.M.														Watch 10 secs. slow at 8.28.
	8	30	Boston.	8	31	20	134	54.	54.	----	----	----	----	----		4.158		
			Prison Point.	8	34	0	133	81.	135.							6.237		Oiled cylinders.
															18.2		389.2	
			B&M. Crossing.	8	36	35	142½ x	27.	162.							2.079		x Valve blowing.
2			Somerville.	8	37	55	142	67.5	229.5		10"					5.198		
2			Curve at "	8	39	10	141	54.	283.5	115.	10				18.0	4.158	583.8	
											10~	220+	3600	40.9				+ Time 40m, Gauge 132 lbs.
3			Everett (8-41-20") 5" A ←	8	41	15	131	94.5	378.	54.	10					7.277		
											10~	270+	4418	50.2*	32.7		227.0	+ Time, 42m, Gauge, 127 lbs. Maximum speed of trip.
5	8	42	Chelsea.	8	44	35	140 x	67.5	445.5	47.	10					5.198		x Valve blowing. Raked fire.
											10~	180+	2945	33.5	15.0		324.4	+ Time, 47m, Gauge, 125 lbs.
6			Revere.	8	48	35	136	67.5	513.	68.	10					5.198		
											10~	240+	3927	44.6				+ Time, 50m, Gauge, 127½ lbs.
			Oak Island.	8	51	15	127	67.5	580.5						37.5	5.198	162.2	
											10~	240+	3927	44.6				+ Time 53m, Gauge, 124 lbs. At end of taking speed, were at long bridge
10			West Lynn.	8	55	0	119	----		34.	10					------		
				arr.	56	45									34.3		....	Stopped from full speed in 1 min, & 10 seconds. Raked fire.
11	8	59	Lynn.	8	59	30	139 x	148.	728.5	0.	14					11.396		x Valve began to blow at 144, & was still blowing at 139 on starting.
															16.4		711.1	
12			Swampscott. (9.8) 0 add. ←	9	3	10	114	148.	876.5	148.	10					11.396		" at 54-35 secs, put link fully forward, at 50 secs put on brake.
				arr.	9	50	124				10~	190+	3108	35.3				+ Time, 5m
											10~	200+	3273	37.2	36.0		177.8	+ " 5m 30 secs, Gauge 102 lbs.
16	9	12	Salem.	9	12	30	140	81.	957.5	37.	10					6.237		At 7m 40 secs shut off by throttle, " 7m 44 ", reverse rod put forward, " 7m 50 ", brake put on.
			Know-nothing	9	15		134	81.	1038.5	51.	10				17.3	6.237	389.2	At Salem, oiled cylinders, and engine outside.
				arr.	19	25	131											
18	9	20	Beverly.	9	20	10	137 x	162.	1200.5	81.	10					12.474		x Valve blowing. Raked fire.
				arr.	26	40												
											10~	160+	2618	29.8	18.5		389.2	+ Time 22m, Gauge 121 lbs. Heavy up Grade. Raked fire.
20	9	26	* North Beverly.	9	27	0	124	108.	1308.5	81.	17					8.316		
				arr.	31	35					10~	184+	3010	34.2	26.1		259.5	+ Time, 27m, Gauge 118 lbs. One long and very heavy up grade.
											10							
22	9	32	Wenham. (9-34-40") 5" sub. ←	9	32	10	139	222.8	1531.3	54.	14					17.156		
											10~	260+	4255	48.4				+ Time 37m, Gauge, 128 lbs.
					41	30			Total for 27 miles		6~	230+	3764	42.8	32.1		214.0	+ " 39m, " , 120 lbs.
27	9	43	Ipswich. Arr.	9	44	10	133			46.								
									Av. lbs per mile,	64			Average lbs. Water per mile run, for 27 miles,				318.9	
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 – Column.

* Flag Station.

* Maximum speed during the trip.

Dat
Date

Miles from Boston
27
30
34
37
39
42
43
46
49
51
56
1

Table VII, continued.

Data from Hinkley Engine No 55, E. R. R., – Down Trip, – 8.30 A.M. Bangor Train.
Date, Friday, Mar 17th, 1876.

TABLE VII – Continued.

At Ipswich { Depth water in tender before filling, 26".
" " " " after ", 41".

Miles from Boston	Train due. Time H	M	Station. leave	Train arrival and leaving – Corrected Time by Watch. H	M	S	Steam Pressure Gauge readings lbs.	– Coal Record. – Wht. of coal fired between Stations lbs.	Aggregate of Weight. lbs.	Pounds of coal per Mile run.	Cyl. Notch Approx inches of Stroke	– Speed. – Revs. per Minute	Feet per Minute	Max. rate Miles per Hour.	Average rate Miles per Hour.	Water & Steam Record. Cubic Feet of Water Evaporated between Stations.	Weight of Water & Steam consumed per Mile. lbs.	Notes. Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc.
	A.	M.	5" entracted						1531.3									
27	9	43	Ipswich.	9	44	10	133	202.5	1733.8							20.756		
											10"–	260+	4255	48.4	22.1		431.7	+Time, 50m, Gauge 109 lbs.
30	9	50	*Rowley.	9	52	20	134	87.8	1821.6	68.	10					9.000		
											10–	190+	3108	35.3	33.9		140.4	+Time, 56, Gauge 107 lbs. Up Grade. Raked fire.
34			*Knights Crossing. (10-1-20") 10 sub.	9	59	25	100	94.5	1916.1	22.	10					9.686		Raked fire.
			Know-nothing.	10	3	0	117	128.3	2044.4			---	-----	-----	23.6	13.151	475.0	
				Arr.	7	0												
37	10	05	Newburyport.	10	9	20	136	148.5	2192.9	74.	10					15.221		At Newburyport, – depth water in tender, 34 3/4".
											10–	230+	3764	42.8	26.7		474.9	+Time 13m, Gauge pressure, 121 lbs. Stirred fire.
39			*Salisbury	10	13	50	119	121.5	2314.4	72.	10					12.454		
											10–	160+	2618	29.8	29.2		259.0	+Time 17m, Gauge, 110 lbs. Heavy up grade.
				Arr	20	0												
42	10	20	*Seabrook	10	20	25	134	175.5	2489.9	41.						17.989		Mail bags. Opened back ash pan damper.
															14.1		1091.0	
43	10	25	*Hampton Falls. (10.28) 15" sub.	10	24	40	138x	108.	2597.9	176.						11.070		xValve blowing. Stirred fire.
											6–	110+	1800	20.5	20.9		230.3	+Time, 29m 30 secs, Gauge 125 lbs. Very heavy up grade.
				Arr.	30	15					21 1/8							
46	10	33	Hampton.	10	32	0	141	162.	2759.9	36.	17					16.605		
											14							
											10–	96+	1571	17.9	25.3		345.4	+Time 34-30, Gauge, 132 lbs. Oiled cylinders. Stirred fire.
				Arr.	39	5												
49	10	40	North Hampton.	10	39	45	138	108.	2867.9	54.	10					11.070		
											10–	170+	2781	31.6	19.5		345.4	+Time, 43m, Gauge 124 lbs. Speed taken at stone overhead bridge. Double track begins.
51	10	47	*Greenland. (10-54-40") 20"s.	10	45	55	141x	189	3056.9	54.	10					19.373		xValve blowing.
								Total for 56 miles			10–	200+	3273	37.2	27.9		241.8	+Time 50m, Gauge 118 lbs. Down grade. Stirred fire, Oiled cylinders.
											10–	110+	1800	20.5	Average, lbs of water per mile, 29 miles.		403.5	+Time, 55 1/4 m, & taken for 1/4 min. Gauge 117 lbs.
56	10	57	Portsmouth. Arr.	10	56	40	125			38.								Accident – bent draw pin.
			Average Steam Pressure for 56 miles, 132					Average, lbs per mile, 64 " lbs for 56 miles, 64										
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 – Column. 21½".

At Portsmouth { Depth water in tender before filling, 21".
" " " " after ", 41 3/8".

* Flag Stations.

No coal taken aboard at Portsmouth.

Table VIII.
Wednesday Mar 15th,
Return trip.

Miles from Portsmouth.
5
7
10
13
14
17
19
22
26
29
1

Data from Hinkley Engine No 55, — Return Trip. — 8.30 A.M Bangor Train.

Date, Wed, Mar 15th, 1876. E.R.R.
Day, dry, chilly, 15°–40°F, Wind, W, & very strong.

TABLE VIII.

Portsmouth { Coal taken on,
Depth water in tender, 40¼"
Number of cars, 7.

Miles from Portsmouth.	Train due Time H	M	Station, leave	Train arrival and leaving. Corrected Time by Watch. H	M	S	Steam Press. Gauge reading lbs.	Coal Record. Wht of Coal fired between Stations lbs.	Aggregate Weight lbs.	Pounds of Coal per Mile run.	Cut off Notch. Approx inches of stroke.	Speed. Revs per Minute.	Feet per Minute.	Max. rate. Miles per Hour.	Average rate Miles per Hour.	Water & Steam Record. Cubic Feet of Water Evaporated between Stations	Weight of Water & Steam consumed per Mile. lbs.	Notes. Oiling, Shutting off, Braking, Grades, Speed, Air-brake press, etc.
	A	.M.	(11.12)					81.+										
	11	18	Portsmouth.	11	26	35	137	283.5	364.5		14"					39.731		Six shovelsful or 81 lbs were put in before leaving Portsmouth. Coal wet before starting.
											10–	160 (9 5 lbs)	2618	29.8				
											10–	180 (9 3)	2945	33.5	22.5		495.8	Raked fire.
5	11	28	*Greenland.	11	39	55	94	141.8	506.3	73.	10					15.456		
															17.3		482.2	
7	11	35	North Hampton.	11	46	50	94	135.	641.3	71.						14.715		
											10–	200 (11 4 lbs)	3273	37.2	30.		306.1	Oiled cylinders. Raked fire.
10	11	42	Hampton.	11	52	50	127	54.	695.3	45.	10					5.886		
															37.9		122.4	
13	11	47	*Hampton Falls.	11	57	35	128	148.5	843.8	18.						16.187		
															12.		1010.1	
14	11	50	*Seabrook.	12	2	35	128	175.5	1019.3	149.	10					19.130		Air-brake pressure fell from 85 lbs to 50 in stopping the train.
											10–	130† (11 9 lbs)	2127	24.2				† Heavy up grade
											10–	‡240 (10 4 lbs)	3927	44.6	28.8		397.9	‡ Up grade.
											10–	220 (10 2)	3600	40.9				
17			*Salisbury.	12	8	50		40.5	1059.8	59.	10					4.415		
	P.	M.		12	12	50												
															30.		137.7	Raked fire.
19	12	5	Newburyport.	12	14	50	133	94.5	1154.3	20.						10.301		
			Know-nothing.					108.	1262.3						14.2	21.772	667.1	
22			*Knights Crossing.	12	27	30	117	148.5	1410.8	68.	10					16.187		Oiled cylinders.
											10–	220 (11 0)	3600	40.9			252.6	
26			*Rowley. arrive at	12		5	122	229.5	1640.3	37.						25.016		
																	520.3	Raked fire.
29	12	28	Ipswich.	12	34	15	118		Total for 29 miles.	77.								Safety valve began to blow off at 142 lbs.
									Average lbs per mile,	62			Average lbs. per mile for 29 miles }				439.2	
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 — Column.

* Flag Station.

† Fired at Portsmouth.

Table VIII continued.

Miles from Portsmouth.
29
34
36
38
40
44
45
46
50
51
53
54
56
1

Data from Hinkley Engine No 55, E.R.R. – Return Trip. – 8.30 A M Bangor Train.
Date, Wed, Mar 15th, 1876.
Day,

TABLE VIII, – Continued.

At Ipswich. { Depth water before filling, 17¼".
" " after " , 42".

Miles from Portsmouth.	Train due Time.		Station.	Train arrival and leaving – Corrected Time by Watch			Steam Pressure.	– Coal Record –			Cut off Notch.	– Speed –				Water & Steam Record.		Notes.
	H	M	leave	H	M	S	Gauge readings. lbs.	Wht. of Coal fired between Stations lbs.	Aggregate Weight. lbs.	Pounds of Coal per Mile run.	Approx inches Stroke.	Revs. per Minute.	Feet per Minute	Max. rate Miles per Hour.	Average rate Miles per Hour.	Cubic Feet of Water Evaporated between Stations	Weight of Water & Steam consumed per Mile. lbs.	Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc.
	P	M					118		1640.3									
29	12	28	Ipswich.	12	40	40	134	195.8	1836.1		10"					30.741		Raked fire.
											10–	150 (9	2454 72lbs)	27.9	25.7		383.7	Upgrade.
34	12	40	Wenham.	12	52	20	103	54.	1890.1	39.	10					8.478		
											10–	170 (10	2781 22lbs)	31.6	27.7		264.5	Heavy up grade.
36			*North Beverly. (1.00)	12	56	40	98	67.5	1957.6	27.	10					10.598		
											10–	220 (10	3600 02lbs)	40.9	25.7		330.1	Oiled cylinders.
38	12	48	Beverly.	1	1	20	118	54.5	2011.6	34						8.557		
			Know-nothing.					40.5	2052.1						19.1	6.359	465.4	Raked fire.
					7	35	124											
40	12	58	Salem.	1	9	0	143x	216.0	2268.1	128.	10					33.912		xValve blowing.
															31.3		423.1	
44			Swampscott.	1	16	40	99	0.		54.	10					------		
					19	15	118				10–	200 (98	3273 22lbs)	37.2	23.2			
45	1	11	Lynn.	1	20	0	128	40.5	2308.6	0.						6.359		Oiled Cylinders.
															12.7		396.8	
46			West Lynn.	1	23	25	114	114.8	2423.4	41.	10					18.024		
																		Raked fire.
			Oak Island,	1	27	30	98	0.			10	-----	-----	-----	30.5		281.1	
50			Revere.	1	31	15	98	67.5	2490.9	29.	10					10.598		
				Arr.	35	15									12.9		661.3	
51	1	28	Chelsea.	1	35	55	113	40.5	2531.4	68.						6.359		Stopped 40 secs.
															32.7		192.4	
53			Everett.	1	39	35	104	13.5	2644.9	20.						2.120		
			Curve at Somerville	1	41	55	100	0.			---	----	----	----	14.7		132.3	
					43	40												Raked fire.
54			Somerville.	1	44	0	101	27.	2571.9 Total for 56 miles.	14.						4.239		
			Prison Point.	1	46	35	110				---	----	-----	----	22.8		132.3	Took 35 secs to stop.
56	1	45	Boston, Arr.	1	49	15	110			14.			lbs. of water per mile run. Average for 27 miles }				-333.0	Watch 15 sec fast at 1.55 P.M at Boston.
			Average Steam Pressure for 56 miles				115	} Average lbs per m.		47								
							Average lbs of coal per mile for 56 miles			55								
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 – Column.

At Boston { Depth water in tender on arrival, 1'-11¼".

*Flag Station.

Data from H

Date, Thursda

Day,

42"

Table IX.
Thursday Mar 16th,
Return Trip.

Miles from Ports" mouth.	Train due Time. H	M.
	A.	M
	11	
5		
7		
10		
13		
14		
17		
19		
22		
26		
29		
1		

Data from Hinkley Engine No 55; E. R. R. — Return Trip, — 8:30 A.M. Bangor Train.
Date, Thursday, Mar 16th, - 1876.
Day,

TABLE IX.

At Portsmouth { Coal taken on, 2 tubs = 800 lbs.
Depth water in tender after filling, 42".
Number of cars, 6.

Miles from Ports"month.	Train due Time.		Station.	Train arrival and leaving — Corrected Time by Watch			Steam Pressure. Gauge readings.	— Coal Record. —			Cut" Notch	— Speed. —				Water & Steam Record.		Notes.
	H	M	leave.	H	M	S	lbs.	Wht. of coal fired between Stations lbs.	Aggregate Weight. lbs.	Pounds of coal per Mile run.	Approx inches Stroke	Revs. per Minute.	Feet per Minute	Max. rate. Miles per Hour.	Average rate. Miles per Hour.	Cubic Feet of Water Evaporated between Stations.	Weight of Water or Steam Consumed per Mile. lbs.	Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc.
	A.	M																
	11	18	Portsmouth.	11	22	45	137×	189.	189.		6"					25.515		Oiled cylinders. Raked fire. × Register in firedoor. Safety valve blowing off.
											6 ~	250+	4090	46.5				+Time, 29 m, Gauge, 123 lbs.
											6 –	180+	2945	33.5	26.3		318.4	+Time, 31 m, Gauge, 120 lbs.
											6 ~	180+	2945	33.5				+Time, 32 m, Gauge, 118 lbs.
5	11	28	*Greenland.	11	34	10	130	108.	297.	22.						14.580		At 33 m 10 secs. shut off steam, upgrade. 5 secs later put reverse lever forward, stopped at 33-56 secs.
											10 ~	150+	2454	27.9				
											6 –	210+	3437	39.1	19.5		454.9	+Time 36 m, Gauge 117, Up grade. +Time, 37½ m, Gauge 114, at bridge.
7	11	35	North Hampton.	11	40	20	127	54	351.	22.						7.290		Raked fire. Shut off at 39, link forward, 39-52, stoped at 39 m 45 secs. Stopped in 45 secs from full speed.
											10 –	90⊕	1472	16.7				
											10 –	220+	3600	40.9				⊕Time, 42 m, Gauge 124 lbs. Very heavy up grade.
											10 ~	250+	4090	46.5	27.3		151.6	+Time, 44 m, Gauge, 130 lbs.
10	11	42	Hampton. (11.47)	11	46	55	133	54	405.	18.	10					7.290		+ " 45 " " , 123 " . Raked fire.
															39.1		151.6	
13	11	47	*Hampton Falls.	11	51	30	129	108.	513.	~~7~~8.						14.580		
															12.0		909.8	Raked fire.
14	11	50	*Seabrook.	11	56	30	138	108.	621.	108.	10					14.580		
											10 –	180+	2945	33.5				+Time 11-58, Gauge, 133 lbs. Up-grade.
											6 ~	220+	3600	40.9				+Time, 12 M, Gauge, 130 lbs, Level.
											6 –	260+	4255	48.4	29.3		303.3	+Time 12-1m, " , 127 lbs.
17			*Salisbury.	12	2	40	125	40.5	661.5	36.	6					5.468		at Newberryport, depth water in tender 30 3/8" when still.
	P.	M.													30.0		170.6	
19	12	05	Newberryport.	12	6	40	137×	27.	688.5	20.	10					3.645		× Valve blowing — taken at 12-9-50. Oiled cylinders.
			Know-nothing.				134	54.	742.5		10				} 17.3	7.290	227.4	Raked fire. Branch of B. & Maine R.R.
22			*Knights Crossing.	12	17	5	133	128.3	870.8	27.	6							
											6 ~	200+	3273	37.2	37.9	17.321	270.2	+Time, 19 m, Gauge, 129 lbs. Up grade good. Raked fire.
26			*Rowley.	12	23	25	134	135.	1005.8	32.	10					18.225		Stopped.
									Total for 29 miles.		10 –	200+	3273	37.2	28.3			+Time 26 m, Gauge, 129 lbs.
29	12	28	Ipswich. Arr.	12	29	45				45.							379.1	
									Average lbs per m.	35.						Average lbs. of water per mile.	-- 333.7	
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 – Column.

* Flag Stations.

Table IX continued.

Data fro

Date, Thu

Day, dr

Miles from Ports-mouth.	Tra d T
29	
34	
36	
38	
40	
44	
45	
46	
50	
51	
53	
54	
56	
1	

Data from Hinkley Engine No, 55; E. R.R. – Return Trip, – 8.30 A.M. Bangor Train.
Date, Thursday, Mar. 16th, 1876.
Day, dry, pleasant, Wind, E.

TABLE IX, – Continued.

At Ipswich { Depth water in tender before filling, 24½".
" " " " after ", full

Miles from Ports" mouth.	Train due Time.		Station.	—Train arrival and leaving— Corrected Time by Watch.			Steam Pressure.	—Coal Record.—			Cut" Notch.	— Speed. —				Water & Steam Record.		Notes.
	H	M.	leave	H	M	S	Gauge readings lbs.	Wht. of coal fired between Stations. lbs.	Aggregate Weight lbs.	Pounds of Coal per Mile run	Approx. inches Stroke.	Revs. per Minute	Feet per Minute	Max. rate Miles per Hour.	Average rate Miles per Hour.	Cubic Feet of Water Evaporated between Stations	Weight of Water or Steam consumed per Mile. lbs.	Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc
	P.	M							1005.8									Second valve blew off at 144 lbs.
29	12	28	Ipswich.	12	36	10	139	243.	1248.8		10"					35.235		
											10~	220+	3600	40.9	28.8			+Time, 41m, Gauge, 130 lbs.
34	12	40	Wenham.	12	46	35	134	54.	1302.8	49.	10~	220+	3600	40.9			439.7	+ " , 42m, " , 129 lbs.
											10					7.830		Stopped 35 secs.
											10~	220+	3600	40.9				+Time, 49m, Gauge, 122 lbs, Up-grade.
															32.7		244.3	
											10~	210+	3437	39.1				+Time, 50m, " , 118 lbs.
36			*North Beverly.	12	50	15	117	40.5	1343.3	27.	6					5.873		
				ar.	54	45												
											6~	290+	4745	53.9*	26.7		183.2	+Time, 53m, Gauge, 126 lbs. Down grade of 43' to mile. Maximum speed of trip.
38	12	48	Beverly.	12	55	45	138	40.5	1383.8	20.	10					5.873		
											---	200+	3273	37.2				+Time 58m, Gauge Pressure, ---, speed taken while slowing down.
			Know-nothing.	12	59	15	136	27.	1410.8		10				18.5	3.915	305.4	Fire stirred.
				ar. 1	2	15												At Salem, – depth of water in
40	12	58	Salem. (1.06)	1	5	15	141	108.	1518.8	34.	10					15.660		tender, 33¾".
											10~	180+	2945	33.5	33.9		244.3	+Time, 1-8m, Gauge, 134 lbs.
44			Swampscott.	1	12	20		27.	1545.8	27.	10~ 6	200+	3273	37.2		3.915		+Time, 9m, Gauge, 136 lbs.
				ar.	14	40	146								25.7		244.3	Large safety valve set approx. for 145 lbs, small one 140 lbs, & should blow down to 130 lbs.
45	1	11	Lynn.	1	16	10	143	13.5	1559.3	27.						1.958		
															24.0		122.2	
46			West Lynn.	1	18	40		67.5	1626.8	14.	10~	200+	3273	37.2		9.788		+Time, corrected, 20m 20 secs, Gauge, 132 lbs.
											6~	200+	3273	37.2				exact at long bridge +Time, 22, Gauge pressure, 125 lbs, at bridge.
			Oak Island.	1	24	15	126	40.5	1667.3		6				31.6	5.873	244.3	Raked fire.
											6~	200+	3273	37.2				+Time 24m, Gauge, 124 lbs.
50			Revere	1	26	15	124	81.	1748.3	27.	6					11.745		
				ar.	29	25												
											6~	200+	3273	37.2	18.9		732.9	+Time 27m, Gauge 119 lbs.
51	1	28	Chelsea.	1	30	5	134	27	1775.3	81.						3.915		Raked fire.
											10							
															34.9		122.2	
53			Everett.	1	33	30	122	-----			6							
											6~	240+	3927	44.6				+Time, 33m 50 secs. corrected, Gauge, 134 lbs. Race with Maine R.R.
			Curve at Somerville.	1	35	10	131	-----			6				28.8	------	------	Raked fire.
				ar.	35	35												Oiled cylinders.
54			Somerville.	1	37	50	142	54.	1829.3	9.	14					7.830		
			Prison Point.	1	41	10	133	40.5	1869.8						26.1	5.873	427.6	
56	1	45	Boston, Arr.	1	42	25			Total for 56 miles.	52					Average lbs. per mile		275.9	Watch 20 seconds slow at 1.45 P.M.
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 – Column.

Average steam pressure for 56 m's, 133. } Av. lbs per mile, 33
Average lbs. of coal per mile for 56 miles, 34

At Boston { Depth of water in tender on arrival, 26."

*Flag Station.

*Maximum Speed observed during the trip.

Dat
Date
Day,

Miles from Pratt, north.
5
7
10
13
14
17
19
22
26
29
1

Table X.
Friday Mar 17th
Return Trip.

Data from Hinkley Engine No 55, E. R. R. — Return Trip, — 8.30 A.M. Bangor Train.
Date, Friday, Mar 17th, — 1876.
Day, wet, icy. Wind E.

TABLE X.

At Portsmouth. { Coal taken on, none.
Depth water in tender after filling, 41 3/8" 0 1/2"
Number of cars, 7.

Miles from Portsmouth.	Train due Time. H	Train due Time. M	Station. leave	Train arrival and leaving — Corrected Time by Watch. H	M	S	Steam Pressure Gauge readings lbs.	Coal Record — Wht. of coal fired between Stations lbs.	Coal Record — Aggregate Weight. lbs.	Coal Record — Pounds of Coal per Mile run.	Cyl" Notch. Approx inches of Stroke	Speed — Revs. per Minute	Speed — Feet per Minute.	Speed — Max. rate. Miles per Hour.	Speed — Average rate. Miles per Hour.	Water & Steam Record. Cubic Feet of Water Evaporated between Stations	Water & Steam Record. Weight of Water as Steam consumed per Mile. lbs.	Notes. Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc.
	A.	M	(11-21-20") 26 s. ←					47.3										Valve began to blow off at 140 lbs. Shook great.
	11	18	Portsmouth.	11	24	25	135	418.5	466.8							48.909		31 shovelsful. put in.
											10" –	126+	2061	23.4				Weather clearing off.
											10 –	270+	4418	50.2				+Time, 26 m, Gauge, 127 lbs. Very heavy up grade.
															29.5		610.4	+ " , 31 m, " , 109 lbs. " " .
											10 –	240+	3927	44.6				+ " , 32 m, " , 113 lbs.
5	11	28	*Greenland.	11	34	35	122.	148.5	614.3	93.	14					15.593		
											10 –	150+	2454	28.3				+Time, 37 m, Pressure, 108 lbs. At stone overhead bridge.
				arr.	40	25					10 –	250+	4090	46.5	20.6		455.3	+Time, 39 m, Pressure, 106 lbs. Partially on an up grade and on the other side of bridge a down grade.
7	11	35	North Hampton.	11	40	45	115	94.5	708.8	74.	14					9.923		Oiled cylinders.
											14 –	110+	1800	20.5	31.9		206.4	+Time, 43 m, Gauge, 104 lbs. Heavy up grade.
10	11	42	Hampton.	11	46	25	110	121.5	830.3	32.	10					12.758		Raked fire.
			(11-48) 30" sub. ←								10 –	250+	4090	46.5				+Time, 50 m, Gauge, 103 lbs.
											10 –	250+	4090	46.5	26.1		265.3	+Time, 51 m, Gauge, 98 lbs.
13	11	47	*Hampton Falls.	11	53	20	108	189.	1019.3	41.	10					19.845		
14	11	50	*Seabrook.	----	----	----	----	----			10 –	130+	2127	24.2				+Time, 57 m, Gauge, 102 lbs. Very heavy up grade. No stop made. Raked fire.
															33.9	----	309.5	
												----	----	----				
17			*Salisbury.	12	0	25	103	40.5	1059.8	47.	6					4.253		No stop.
	P.	M.		arr.	4	15						---	----	----	31.3		132.7	Cloudy but dry.
19	12	05	Newburyport.	12	6	40	138	60.8	1120.6	20.						6.384		At Newburyport — Depth of water in tender, 28". Oiled cylinders.
			Know-nothing.	12	9	55	136	20.3	1140.9	[illegible]		----	----	----	24.8	2.132	177.2	Raked fire.
22			*Knights Crossing	12	13	55	120	108.	1248.9	27.	6					11.340		Cylinder cocks opened.
			(12-04-40) 35" sub. ←															
											6 –	200+	3273	37.2	38.3		176.9	+Time, 17 m, Gauge, 109 lbs. Taken on the up grade to cut. Cylinder cocks opened.
26			(*)Rowley.	12	20	10°	120	108.	1356.9	27.	10					11.340		Stopped. Register in fire-door open.
											10 –	200+	3273	37.2	27.7		235.9	Foggy. +Time, 24 m, Steam pressure, 120 lbs.
29	12	28	Ipswich. Arr.	12	26	40			Total for 29 miles	36.								
									Average lbs per m.	44					Average lbs. of water per mile, for 29 miles, -- }		...265.5	
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 — Column.

* Flag Stations.

Dat
Date

Miles from Portsmouth.
29
34
36
38
40
44
45
46
50
51
53
64
56
1

Table X, continued.

Data from Hinkley Engine No 55, E.R.R. — Return Trip. — 8.30 A.M. Bangor Train.
Date, Friday, Mar 17, — 1876.

TABLE X, — Continued.

At Ipswich { Depth water in tender before filling, 23¼".
" " " " after " , 41¼".

Miles from Portsmouth.	Train due Time. H	Train due Time. M	Station. leave	Train arrival and leaving — Corrected Time by Watch H	M	S	Steam Pressure. Gauge reading. lbs.	Coal Record. Wht. of coal fired between Stations lbs.	Coal Record. Aggregate Weight. lbs.	Coal Record. Pounds of coal per Mile run.	Cut off Notch. Approx inches of Stroke.	Speed. Revs. per Minute.	Speed. Feet per Minute.	Speed. Max. rate. Miles per Hour	Speed. Average rate. Miles per Hour.	Water & Steam Record. Cubic Feet of Water Evaporated between Stations	Water & Steam Record. Weight of Water or Steam consumed per Mile. lbs.	Notes. Oiling, Shutting off, Braking, Speed, Air Brake Pressure, etc.
	P.	M.	35" sub.						1356.9									
29	12	28	Ipswich.	12	32	40	138	216.	1572.9		10"					29.808		Began to snow — Stirred fire.
			(12-41-20) 40" sub. ←	Arr.	42	50					10~	220+	3600	40.9	29.5		371.9	+Time 39m, Steam pressure, 99 lbs.
34	12	40	Wenham.	12	44	5	123	74.3	1647.2	43.	10					10.253		Oiled cylinders from cab.
											10~	170+	2781	31.6				+Time, 47m, Gauge, 113 lbs. Very heavy up-grade.
															28.8		319.9	Raked fire
											10~	200+	3273	37.2				+Time, 48m, Gauge, 106 lbs.
36			*North Beverly.	12	48	15	106	27.	1674.2	37.	6	360+	5891	67.0 *		3.726		+Time 50¼m. Counted 90 revs in one fourth minute — estimated.
				Arr.	52	30					6~	300+	4909	55.8	28.1		116.3	+Gauge 113 lbs. Taken immediately after preceding. Counted 150 revs in ½ minute. The greatest speed reached.
38	12	48	Beverly.	12	53	25	122	81.	1755.2	14.						11.178		
				Arr.	56	45												
			Know-nothing	12	57	0	121	33.8	1789.0			-----	-----	-----	18.2	4.664	494.2	Snowing very fast. Oiled engine outside.
				Arr. 1	0	0												
40	12	58	Salem.	1	1	50	139 ×	270.	2059.	57.	10					37.260		×Blew off at 139 lbs. and pressure jumped to 141 lbs.
			(1.8) 45 sub. ←								10~	170+	2781	31.6	30.5		581.3	+Time 6 mins, Pressure, 121 lbs. Up grade, though not very heavy
44			Swampscott.	1	9	40	102	--0--		68.	10					------		
				Arr.	12	20	112				10~	120+	1963	24.1	22.5		------	Raked fire +Time, 11m, Gauge 104 lbs.
45	1	11	Lynn.	1	13	30	129	40.5	2099.5	0.	10					5.589		Oiled cylinders.
											10~	70+	1145	13.0	23.2		348.8	+Time 16 min.
46			West Lynn.	1	16	5	123	87.8	2187.3	41.	10					12.116		Raked fire.
											6~	200+	3273	37.2				+Time, 19m, Gauge 116 lbs.
			Oak Island.	1	20	45	111	27.	2214.3		6				31.3	3.726	247.1	
50			Revere.	1	23	45	108	27.	2241.3	29.	6					3.726		
											6~	200+	3273	37.2	15.7		232.5	+Time 25½m, Gauge 107 lbs.
51	1	28	Chelsea.	1	27	35	120	47.3	2288.6	27.	10					6.527		Raked fire.
											10~	160+	2618	29.8	31.3		203.6	+Time, 31m, Gauge 112 lbs.
53			Everett.	1	31	25	111	60.8	2349.4	24.						8.390		
			Curve at Somerville	1	33	25	106	13.5	2362.9		17	----	----	----	19.5	1.863	639.8	Slowed down for draw. Raced with the Maine & beat them. Rate, about 250 revs. per minute.
			(1-34-40) 50" sub. ←	Arr.	34	30												
54			Somerville.	1	34	50	116	------	Total for 56 miles	74.	17					------		
				Started,	37	30	113											
			Prison Point.	1	41	50	133	------		0		-----	-----	-----	12.9	-----	------	‡Delayed at Prison Point by an East Boston Freight train on the Fitchburg Crossing.
56	1	45	Boston. Arr.	1	44	10				0					Average lbs. for	27 miles	296.3	At Boston. Watch 50 secs. fast at 1.48 P.M. Estimated coal left in tender, — 2 tubs.
1	2		3	4			5	6	7	8	9	10	11	12	13	14	15	16 — Column.

Average Steam Pressure for 56 miles, 119 } Av. lbs per mile, 32
Average lbs of coal per mile for 56 miles, 38

At Boston { Depth of water in tender on arrival, 23½".

*Flag Station.

*Maximum speed observed during any of the trips.

The carrying of a train from Boston to Portsmouth means so many gallons of water and pounds of coal consumed. These Tables state what these amounts are. They show, primarily, the facts concerning the actual manner in which our best locomotives are, at the present time run. From them we can deduce others, such as the equivalent Horse Power developed, the effect of the weather and the velocity of the wind in producing the total Train Resistance which has its part in determining the actual Efficiency. Although the stations come pretty close together in respect to time, when not employed in any other direction the speed was usually taken by counting the oscillations of the cross-head. At the higher speeds, from 5 to 6 revolutions or over 98 feet, per second, even; the momentum of the engine carried it lightly over slight inequalities in the rails and it was very rarely that much thumping or pounding occurred. It will be seen that hardly any of the data are exact. For, in the first place, it all had to be observed by one person, and where several things had to be observed at once, such as the time, the speed and the steam pressure, a difference in the time of taking the three with the accompanying changing conditions, was perceptible. And, second, no more exact *methods* of taking the data, as was suggested by other students in my class, such as weighing the coal every time the fireman happened to fire up, which was about once in half a minute at full speed, measuring the water fed, by a gauged vessel, the speed by any of the complicated Speed Recorders, or of the Tractive Power by a Dynamometer, all of which, with the addition of indicator diagrams taken from the cylinder, I should have been most happy to have attempted, could be followed, for I could not interfere in anyway with the duties of the engineer in the running of his engine. The memoranda were therefore only Observations which could be made in the cab and do not constitute Experiments. It was therefore useless to apply to them the refined methods of correction employed in the Physical Laboratory, such as the method of the sum of the least squares for errors of observation, or to compute the Probable Error by the process of differences and 'weights'; which would form an exceedingly interesting investigation, for the limits of error are too great for these, and it is from the fact that no such data exist in books and that they represent the actual conditions as nearly as I could take them that I venture to make their discussion form so large a part of my before lengthy thesis. Precisely what the columns of these tables represent will now be stated.

Miles to or from Boston, column 1. These miles were obtained from the published time table of the Eastern Road. I was assured by an official of the Road that these distances were accurately given, "engineers miles". Nevertheless, on finding such gross mistakes in the time table as, that from Boston to Chelsea was 5 miles, and Chelsea to Boston but 4, and that on the down trip Salisbury was 39 miles from Boston while on the return it was but 38, a decided doubt was cast on these figures and application was made to the Chief Engineer of the Road,* at Salem for profile maps of the road by which I could get more accurately the distances and also the Grades at any points of the road at which the speed was taken. Being disappointed in this, as not even a regular

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*Mr. Chas. E. Putnam.

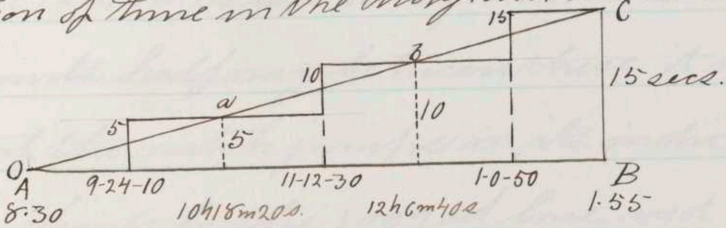
survey of the road has been made since its construction, I was obliged to take the time table distances as a basis and remedy the inaccuracis from my own knowledge of the road.

Columns 2 and 3 require no explanation further than to say that where the times are given in column 2, a stop was made, and there were no others unless specially mentioned in the column of notes.

Train Arrivals and Departures, Corrected Time by Watch, column 4. These were noted by the second hand of the watch at the instant of full stop and starting. Where two times are given opposite the name of one Station the upper one signifies the stop, the lower the start, and opposite in column 5 are the Steam Gauge pressures at those instants. In some cases, instead of noting the time of arrival, the duration of time during the stop is noted, in the last column, and in other cases not noted at all, as the time could be estimated from the others with sufficient accuracy

— Correcting the Time by the Watch, Col. 4. —

if needed. Although the watch had been just previously regulated, the jar of the locomotive influenced its rate and it was necessary to apply a correction for the times in order to calculate the average speeds in column 13, at different portions of the road. This was done as follows:– From Tables V and VIII ~~on~~ Wednesday, Mar 15th, it was noted at Boston before leaving that the watch had been carefully set by the Depot clock, which gives correct Cambridge time, so that it practically indicated exact Railroad Time at 8.30 A.M. In the latter table it is also noted that on the return to Boston the watch was 15 seconds fast by the clock at 1.55 P.M. Let the horizontal line AB, represent this duration of time in the diagram below.



The length of this line represents the interval, (12 M − 8.30) + 1.55 = 5 hrs 25 min. At the end of this interval the watch was 15 secs fast and this is represented by the ordinate or positive distance BC, above the line AB. Now at the beginning the watch coincided with the clock at 0, hence by drawing the diagonal line AC we represent the rate of gain of the watch by the length of the ordinate at any point, on the assumption that this gain was uniform in its rate during the whole interval, and hence to obtain the true time we must subtract from the indication of the watch at any time, a number of seconds represented by the length of the ordinate at the same point. Now the limits of error for the time, I have taken at 5 secs, and hence at the point a, $= \frac{AB}{3} = \frac{5 \text{ hrs } 25 \text{ min}}{3} =$ 1h. 48m 20 secs which added to 8h 30m gives the time 10h 18m 20 secs at which the watch is just 5 secs. too fast. And at 1h 48m and 20 secs more or 12h, 6m 40 secs it is just 10 secs too fast. Now at points halfway between these it is assumed that the watch jumps in its indications 5 secs as shown by the jogged line, and continues for an equal distance on either side of these points 0 a b c which give the true times of this increase. So that no correction is made to the watch indications is made from 8.30 to 9.24 when 5 secs are is subtracted from all till 11.13 when 10 sec is subtracted etc, and similar corrections were made for the other tables. The amount by which the times are corrected are given in the Tables opposite the times*.

Steam Pressure, Gauge Readings, column 5. The gauge was of the American Steam Gauge Companies make, a Bourdon Gauge with Lane's improvement and similar in all respects to that described and illustrated in Part IV. The readings were taken as soon as possible after the times were jotted down, varying from 3 to 5 or even 10 secs only behind time. It has been noticed since these readings were taken that with no steam raised in the boiler the gauge hand indicated 6 or 8 ozs., but this is usual in locomotive gauges, on account of the very stiff springs used to prevent the jarring from making the motion of the hand unsteady. In this column is seen the great and often sudden variations of pressure in locomotives, it hardly remaining the same for two consecutive seconds. Where the steam is used almost as fast as generated, its sensitiveness to the

*This method is similar to that followed in Pumping Engine Test at Providence, Dec 1875.

coal thrown on the fire is apparent. The pressures used on the Eastern Road are supposed to be 140 lbs for First Class engines and 120 lbs for second class, the class depending upon the length of time the locomotive has been in service, and this one being in the former. The safety valves of this engine were set one to blow off at 130 lbs and the other at 135, and in the tables the great variations from this state of affairs is seen, in several instances rising to 144 lbs, and in one instance *beginning* to blow off at *144½*, Table VI, and in another case in the same table stopping at 133 lbs. In Table VIII, the pressure at Salem rose 19 lbs in 1 min. 25 secs. From the averages for each trip of 56 miles we notice the difference produced in the steam pressure by the day, Wednesday being very windy, the average is lower for the return trip as the wind was West and against the train, on the second day it is about the same both ways, Tables VI and IX, or 131 & 133 lbs much higher than on the preceding day when it was 127 and 115, and on the third day it was 132 lbs down and but 119 up, the wind as we see affecting it very much on the marshes

— Coal Record. —

between Lynn and Oak Island.

Coal Record, *Weight fired between Stations*, column 6. This was found in an original and what may be considered perhaps, a very rough manner. The times of firing between every two stations were noted, in number, and the equivalent number of full shovelsful of coal estimated. That is, the fireman would throw in from one to three shovelsful at a time and then in perhaps half a minute more, two more etc, and whether these amounted to 1½ or 2 full shovelsful was estimated and noted, and after a little practise this could be done quite accurately, so that at all events the *relative* quantities thrown in at different parts of the road is known if not the absolute, for practically the firing was quite even. The shovel full of coal was weighed on the scales at the Round House before starting, the coal was in the same condition as to dampness as when used on the Road, and the record reads;—

Weight of the shovel *full* of coal, ... 21 lbs.

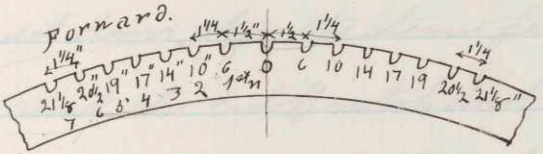
" " " " empty, ... 7½ "

Weight of coal contained in one shovelful, 13½ lbs.

— Cutoff Notch, col. 9, — Speed, cols. 10, 11, and 12. —

The coal record was found using this number which was verified by several weighings. Column 7, the aggregate coal fired shows the great variation in the amount of coal burned in doing the same work on consecutive days. The only difference in the conditions being that of the wind and weather.* On Wednesday during the down trip nearly half a ton more coal was burned than on Thursday and on Friday, 1133 pounds more. Column 8 shows the same variation.

Cutoff Notch, column 9, This column gives only a general idea of the point at which the steam was cutoff in the cylinder. The reverse quadrant had its notches marked as follows. See also plate D Fig. 114. With the original



valve these notches were doubtless marked and cut quite accurately but as the valve had been changed these numbers can be considered only as approximations.

Speed, columns 10, 11 and 12. These were obtained by counting the revolutions of the drivers for half a minute and multiplying this by two gives the revolutions per minute in col. 10. In taking these a full minute was not used on account of the liability of

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*Note. We had the same fireman on Wednesday and Friday but a different one on Thursday.

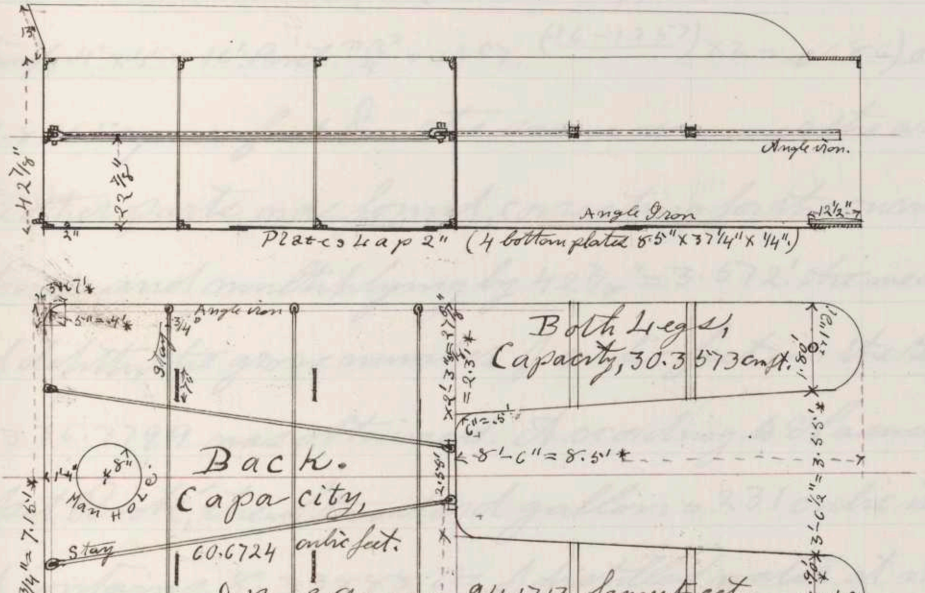
losing the count, and besides the speed was constantly changing and also the character of the road. It was the intention to take the maximum speed at least once between every station. This was done in this way. When it was thought that the engine was at its maximum speed the time was jotted down about 10 secs. before an even minute. A straight piece of track was also selected, or sometimes a heavy grade. Precisely on the even minute, watch in hand, the counting was commenced, and after a little practice the watch could be glanced at to see whether the time was up or not, and the counting continued mentally without missing a count. At the end, the number was set down, then the steam pressure as quick as it could be read, the cutoff notch and any remark, if taken on an exceptional grade. The feet travelled per minute was found by multiplying the number of revolutions by the circumference of the driving wheel, viz. $2\pi r = \pi d = 3.141592 \times 62.5'' = 196.35'' = 16.36$ feet, and the rate in miles per hour by multiplying the feet travelled per minute by 60, to obtain the feet per hour, and dividing by 5280, the number of feet in a mile.

In computing the average speed between the stations, (Column 13), the difference of the times was taken, reduced to seconds, divided by the number of miles between the stations, which gave the number of seconds in which one mile was run; and 3600 (= 60' × 60"), the number of seconds in an hour, divided by it, which gave the average rate in miles per hour. Where the time of stopping was noted, that is taken in computing these average speeds. The highest average speed during any of the trips, (throwing aside that in Table V which is doubtful), was that between Hampton and Hampton Falls, a distance of 3 miles, on Thursday, Return Trip (Table IX), when 39.1 miles per hour was attained. This was on a very heavy down grade, as the other Tables show, equal to 43 ft. per mile. In the column of maximum rates there are three that indicate a speed of over 50 miles per hour, 50.2 miles (Table VII,), 53.9 (Table IX), and one at the astounding rate of 67 miles per hour. (Table X continued.). In order that the fact that this was really attained may be undoubted we will mention the circumstances attending it. The road was between North Beverly and Beverly which has a down grade of at least 40 feet to the mile, the cut off was 6", the throttle wide open, and as will be seen, the train was late and the engineer endeavoring to make up lost time. It will be noticed that 360 revolutions in a minute or 90 in one fourth minute is about as fast as a person can count. In fact, this could not have been audibly counted, 6 times per second, but was partly estimated. The number of turns could be estimated by the eye when, perhaps, they could not be counted, and the high speed obtained immediately afterward, for a check leaves not a doubt in my mind that this speed was actually realized. It was calculated as follows;- 16.36' × 360 = 5889.6 feet per minute. To this, as the speed was over 200 revs. a foot is to be added to make up for decimal places omitted, viz 16.3625 ∴ 5889.6 + 1 = 5891. which multiplied by 60 gives 353,760 as the feet per hour and dividing this by 5280 (ft. per mile), we get 67 miles per hour. In all calculations in this thesis, it may be mentioned, that whenever the rejected decimal places were one half, .5, or over, that of the next figure the next larger number was invariably taken.

Water and Steam Record, (Columns 13 and 14).

The datum taken by which this has been obtained was the depth of water in the tender at several points along the road. This was obtained, on the first day by inserting the firemans broom handle into the man-hole of the tender and then measuring the length of the part wet. Afterwards a notched stick graduated to quarter inches was used with an increase of accuracy. To make these observations of any use, it was of great importance that the capacity of the tender should be accurately determined. The following diagrams represent the result finally determined upon, and also the construction and internal bracing of the tank.

of Tender Tank of Hinkley Engine No. 55 E.R.R.



(Corrected Capacity of Tank, 2,502.4 Standard gallons.)
Scale, 1/4" = 1'.

This tender is of unusual length and capacity, being nearly a foot longer than ordinary tenders of 2000 gallons capacity, and a 2500 gallon tank.

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*By measurements.

— Calculations of Capacity of Tank. —

To obtain its capacity with more accuracy, the working drawings were used, access being had to them at the Hinkley Works, and in addition actual measurements were taken with a steel tape, of every accessible part. These, the more important of which were repeated several times have been mainly followed in calculating its capacity, and those upon the drawings have served rather as checks. The area of the back was found to be 8.5208' × 7.15' (= 60.9237 sq.) — (corners, r = .4'. Rectangle .4' × .4' = .16'. Circle. $\frac{\pi r^2}{4}$ = .1257. (.16 − .1257) × 2 = .0686).0686 = 60.8551 square feet. In the same manner the area of the other parts was found, correcting for the curved portions and multiplying by 42 7/8" = 3.572' the measured depth, the gross number of cubic feet in the tender, 336.3799 was obtained. According to Haswell's Pocket Book, "the Standard gallon = 231 cubic inches and contains 8.33888 lbs. of distilled water at its maximum density, 39.1° F., the barometer being 30"." Hence there are $\frac{1728}{231}$ = 7.4805 gallons in a cubic foot. Multiplying our result by this the gross capacity of the tank is 2516.2898 gallons. Now this is diminished by the volume of the internal staying, and although it was supposed that this would be inconsiderable, a correction was made for this. These stays caused the quantities by which the capacity was to be corrected to be of two kinds. First, a constant correction for every depth consisting of the volume of the perpendicular parts, the upright sheet iron stays and rods, which amounted to 1379.62 cu. in = .795 cu. ft. = 5.94 gallons, and a part consisting of the angle iron two inches high running around the bottom edge of the tank, and the angle iron and horizontal braces which were found to be at a height of 22 7/8" above the bottom. This amounted to 919 cu in = .532 cu ft. $\frac{.532}{2}$ (= .266) × 7.4805 = 1.9898 gallons per inch of height, or 1.9898 × 4 = 7.9529 gallons in all. The ultimate correction was therefore 13.906 gallons and the real capacity 2502.3836 gallons. This process was gone through four times and the capacities found were as follows;– 1st trial, 2453.23 gals., 2d trial, 2519.44 gals; 3d trial, 2465.57 gals. and 4th, <u>2502.38</u> gallons, the differences depending on very slight differences indeed in the measurements and decimal places. Incidentally, the weight of this tender full of water may be here stated. It amounted to 336.3799 cu ft. × 62.4 = 20.990 lbs. or 10.495 tons.

Now, in order to calculate columns 14 and 15, the cubic feet of water corresponding to each inch of height of tank was obtained. Multiplying the area

— Water Record. —

94.1743 sq. feet by .0833′ (=1″) we obtain 7.8445 cubic feet of water in the tender for each inch of height when uncorrected for the staying and angle iron. For the corrected capacity we have 7.8445 − .266 cu. ft. (short per inch) or 7.5785 cu. ft. This is to be used only for the first two inches at the bottom and for from 21⅞″ to 23⅞″ depth. The following table gives the depths of water taken, and coefficients by which these two columns have been obtained.

Water Record.

Miles	Watering Stations.	Tables V and VIII. Wednesday, Mar 15. Depths Taken	Difference.	Cubic feet Water consumed. Pounds of Coal Cubic feet per lb. of coal.	Tables VI and IX. Thursday, Mar 16. Depths Taken	Difference.	Cu. ft. Water Pounds of Coal Cu. ft. water per lb. coal.	Tables VII and X. Friday, Mar 17. Depths Taken	Difference.	Cu. ft. Water. Pounds Coal Cu. ft. water per lb. coal.
27	Boston.	42″	26″	=1521.70 gals. 203.425 cu. ft.	40″	20″	156.358 924.8 lbs.	41″	15″	117.6675 1531.3 lbs.
	Ipswich.	16 41½		1323.1 lbs. coal. .164 cu. ft. per lb. of coal.	20 42¾		.169 cu. ft. 123.55	26 41		.077 156.358
29	10 Newburyport	---	10¼	80.406 cu. ft. 1410.8 lbs.	36	15¾	999 lbs. .124	34¾	20	1525.6 lbs. .1025
	Portsmouth.	31¼ 40¼		.057 cu. ft. 179.8915	27 42		137.2788	21 41½		142.996
29	Newburyport	----	23	1640.3 lbs. .109 cu. ft.	30⅜	17½	1005.8 lbs. .1355	28	18¼	
	Ipswich.	17¼ 42		146.9182	24½ Full: call it 42″.		125.512	23¼ 41¼		.105 1356.9 lbs. 139.1402
27	(Salem)	----	18¾	931.6 lbs. .157 cu. ft.	33¾	16	864 lbs. .145	----	17¾	1006. lbs. .138
	Boston.	23¼			26″			23½		
1	2	3	4	5	6	7	8	9	10	11

It shows the water and coal consumed during all the trips and also the relative amounts used on the same portions of the road on different days. Now, on Wednesday, it seems, 26″ depth of water were consumed in carrying the train from Boston to Ipswich ∴ there are 26 − 2 = 24″ to be multiplied by 7.8445 cubic feet, or

188.2680 cubic feet. Now, the other two inches lying between 21 7/8" and 23 7/8" are to be multiplied by the corrected capacity per inch of depth, which gives $2 \times 7.5785 = 15.1570$. Or, the total number of cubic feet of water consumed in running 27 miles is $188.2680 + 15.1570 = 203.4250$ and this is given in the second line of column 5. Now, the number of cubic feet of water evaporated between the stations, (column 14) is calculated on the supposition that the rate of evaporation is proportional to the coal burned, and in this case, the amount of coal was 1323.1 lbs. Hence $\frac{203.425}{1323.1} = .154$ cubic ft. the average amount consumed per pound of coal, and multiplying this coefficient by the number of pounds of coal burned between the stations, respectively, the cubic feet of water evaporated, given in column 14, were obtained. It will be seen that these coefficients vary greatly on different parts of the road and on different days. Column 15, was obtained by dividing the numbers in column 14, by the number of miles between the stations, respectively, and multiplying by 62.4. The averages differ considerably. The depths of water taken at Newburyport and Salem, where no water was taken on, serve simply as checks. For instance, on Thursday between Ipswich and Portsmouth, a distance of 29 miles, 15 3/4" of water were used or .54" per mile. Now Newberryport being 10 miles from Ipswich, 10 × .54 or 5.40" we might expect to be used in going that distance, leaving 42.75 − 5.4 = 37.35" in the tank. But by the record there was really but 36" at Newberryport, which shows that the evaporation consumption was not exactly proportional to the ~~coal consumed~~ distance run. We cannot discuss all of the interesting facts that can be ascertained by the use of the columns of these tables. A single illustration will suffice. Let us consider the water consumption in running the train from Boston to Portsmouth on Thursday. The volume of one cylinder is 4825.497 cubic inches = 2.792 cu ft. and the cylinder capacity, equal to the steam required per revolution, 11.168 cubic feet. The average steam pressure for the trip was 131 lbs. and the weight of a cubic foot of steam under this pressure being .32592,* 11.168 × .32592 = 3.64 lbs of steam required per revolution. Now the circumference of the wheels being 16.36'; $\frac{5280}{16.36}$ = 322.27 revolutions would be made if there was no slip in a mile. 322.27 × 3.64 = 1173.06 lbs. of steam would be required or $\frac{5}{12}$ths of this, equal to 488.775 lbs. per mile when cutting off at the average amount, 10" of the stroke. Now it appears by column 15, that in but one case was

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*Porter.

this great amount actually used, the averages being but 421.2 and 259.2. To make this difference more plain, for the 56 miles there would apparently be required 488.8 × 56 = 27,372.8 lbs. of water. On the other hand by the Table but 156.358 + 123.55 = 279.9 cubic feet or 17,465.76 lbs. were used. This we know to be a fact. If we attempt to explain this by the reduction of pressure in the cylinder, assuming it to be 20 lbs less or 111 lbs, the weight of a cubic foot of steam would then be but .28625 or $\frac{.28625}{.32592}$ = .878 that in the former case and the apparent consumption would be 24,033 lbs. It seems that the whole tendency is to *increase* rather than diminish this difference, the air brake was working most of the time, any slipping of the wheels would increase it because the valves would open oftener, still more would lose from the safety valves, the blower, leakage of all sorts, and the use of the injector. The only cause that I can assign for it is the saving of steam on down grades and the distance travelled by reason of the momentum of the train after the steam was shut off on approaching stations. The amount of water in the boiler was kept pretty constant during all parts of the trip. Another point to be noticed is the great ap-

Performance of Engines of the Eastern Railroad Company.

Month of January, 1876.

Number of Engine.	Notes. Size of Cyls. Where made.	Kind of Service.	Miles Run.	COAL. TONS.	COAL. LBS.	COAL. Miles run to 1 Ton of Coal.	WOOD. CORDS.	WOOD. Miles run to 1 Cord of Wood.	OIL. PINTS.	OIL. Miles run to 1 Pint of Oil.	WASTE. POUNDS.	WASTE. Miles run to 1 Pound of Waste.
27	Hinkley 16"×24"	Pass. (Name "Chelsea")	549	11	960	50	4/8	----	32	17	11	50
51	Hinkley. 16"×24"	(" "Everett") Freight.	2284	55	300	42	1 5/8	----	108	21	55	42
52	"The Bangor." R.I. Loc. Works 16"×24"	Pass.	1992	32	1960	60	1	----	118	17	50	36
55	Hinkley. (No name.) 16"×24"	"	3016	53	1280	56	1	----	182	17	55	55
56	"St. Lawrence" 13"×20"	"	2382	30	1200	77	1 4/8	----	156	15	33	72
58.	Hinkley. The "Massachusetts" 16"×24"	Freight.	2063	42	2220	48	1 4/8	----	124	17	53	39
60	R.I. Loc. Works The "America" 16"×24"	Pass.	2704	56	2160	47	6/8	----	168	16	55	49
75	Eastern R.R. (No name) 17"×24"	"	2802	46	2160	60			152	18	44	64

Total and Average
for 90 Locomotives on the Eastern Railroad for the Month of Jan,–1876.

Cost of Coal per ton, Average $6.00; per mile run, Average 10.5 cts; Tons of Coal used, Total $2233\frac{2030}{2240}$; Miles run to One Ton of Coal, Average 57

" " Wood per cord, $5.12; " " " , 17.6 " ; Cords of Wood, " , 1,050 ; One Cord of Wood, 29
(On wood burning engines)

" " Oil per pint, .09⅙ ; Pints of Oil " , 8,677 ; One Pint of Oil, 18

" " Waste per pound .08¼ ; Pounds of Waste " , 3,078 ; One Pound of Waste, 50 parent efficiency and evaporative power calculated from these tables. The average evaporation for all the trips is .123 cubic feet or 7.6752 lbs. of water per pound of coal, which gives an apparent boiler efficiency of $e = \frac{E'}{E} = \frac{7.675}{10.92} =$ over 70% while we found its maximum real efficiency to be but .557, on page . This probably shows that there was 14 or 15% priming.

In the column of notes there are a number of facts in regard to the manner of stopping the engine, the air-brake pressure, and time required to stop the train from full speed, which will require no further space here. In order to be certain that the engine which has been selected was not exceptional in any of the conditions under which it worked, similar data have been taken from Engine No 36, "The John Howe," on three Rockport trips, but they have not yet been worked up. The enclosed record of the performance of eight of the best engines upon the Eastern Railroad, this one included, for the Month of January, 1876, will answer the same purpose.

Before we leave this subject, the discussion of these Tables would be incomplete if no allusion were made to the Power exerted by this locomotive, and for the purpose of investigating this let us select the data furnished in Table VIII, on the Return Trip, Wednesday, and the straight and level piece of track, 4 miles in length between West Lynn and Revere. Although the term Horse Power is applicable to Stationary rather than Locomotive Engine, since in general the office of the latter is to draw a load rather than lift a weight through a certain height, its power can be reduced to an equivalent HP, and this is equal to the product of a certain weight attached by a rope to the circumference of one of the driving wheels, lifted through a certain height, and divided by 33,000. Since the power exerted is equal to the work performed this is represented as follows;– $HP = \frac{p \times 2 \times A \times 2 \times S \times N}{33,000.} = \frac{4pASN}{33,000.}$. It therefore depends upon 1st the *effective* pressure, p, per square inch exerted through the whole stroke, the joint area, 2 A, of the two pistons, the length of stroke, S in feet, and the number of revolutions, N, per minute. Now, the average speed, by the Table is seen to have been 30.5 miles per hour. Let us call it 30. In a mile the wheels would make $\frac{5280 \text{ ft.}}{16.36 \text{ ft}} = 322.7$ turns, or $\frac{30}{60} \times 322.7 = \frac{1}{2} \cdot 322.7 = 161 = N$, revolutions per minute. Let us assume the boiler pressure at its maximum of 140 lbs, and let it be reduced 20 lbs. in its transmission to the cylinder. Let it further be assumed that the pressure of 120 lbs. (= 134.7 absolute.) continues constant to the point of cutoff, at 10" of the stroke. The ratio of expansion will hence be $\frac{24''}{10''} = 2.4$, the hyperbolic logarithm of which is .8754. Now dividing this logarithm + 1, by the ratio of expansion 2.4, we obtain .781 by which to multiply the mean absolute pressure, 134.7; during admission. This gives 105.2 lbs for the mean absolute pressure during the stroke, or 90.5 lbs. for the mean effective pressure, p. Hence there will be 201. (sq in Area.) × 90.5 = 18,190.5 lbs. pressure upon each piston, or the entire pressure, P will = 36,381 lbs. The space through which this acts per revolution is 2 × the stroke of 2 feet and multiplying these and the number of revolutions N = 161, we obtain 23,429,364 foot-pounds of work that this engine can perform per minute under these conditions. The equivalent Horse Power is therefore $\frac{23,429,364}{33,000}$, or 710 HP.

The Tractive Power of an engine is limited by the amount of adhesion of its coupled wheels to the rails. This is directly proportional to the weight resting upon them. The weights of the principal parts of this engine, and tender, and also of the train which it was drawing at this time are as follows;—

— Weight. —

Driving Wheel Centres, 4 @ 1480 lbs, ...	5,920 lbs.	
Frame, ------------------------------	3,200 "	
Boiler, with tubes, ----------------	9,800 "	
Weight of water in boiler to 2nd gauge, 50 cubic feet.	3,120 "	
Weight on the driving wheels, ---	40,540 "	
" " " truck " , ---	23,800 "	
Weight of Engine with 2 gauges of water,	64,340 "	= 32.17 tons.
Weight of Tender, empty, ------	20,000 "	
Weight of water contained by tender,	20,990 "	= 10.495 "
Weight of coal " " " ,	6,000 "	= 3. "
	26.990 "	= 13.5 "
Average weight of Coal and Water, = 2/3 maximum, ---,		9. "
Tender loaded with average weight, -----		19, tons.
Total weight of Engine and Tender, ----		51 tons.
Weight of Train, 7 cars, full, @ 22 tons apiece		154 tons.
Total weight of entire train, ----------		205 tons.

The friction of the driving wheels upon the rails or the adhesive weight is usually taken at 1/5th the weight upon them, or, in this case, 8,108 lbs. According to Weissenborn's 'Am. Locomotive Eng.' the number of lbs per ton of load on the driving wheels varies with the condition of the rails and weather as follows; with dry rails 600 lbs. per ton; wet rails, 550; damp, 450; foggy weather, 300; and ice or snow on rails, 200. In this case the rails were dry and the corresponding adhesion which the tractive force could not exceed, $121\overset{62}{64}$ lbs. The Tractive Power is found by dividing the foot-lbs. exerted by the circumference of the wheel. By the Table, the actual steam pressure was 98 lbs. Subtracting 20 lbs. we find, ~~in~~ the same manner as before, that the mean effective pressure is but 57.72 lbs. the foot-pounds of energy developed per revolution but 92,780, and the ultimate horse power that could be exerted under these conditions, but 45.2 HP. The tractive power, or force exerted to move the engine one foot is $T = \frac{2pA \cdot 2S}{2\pi R} = \frac{92,780}{16.36}$ $= \underline{5671}$ lbs. $= R$. This is the condition of uniform motion. The tractive power must balance the resistance. If the resistance, R, is more than T, the engine will not move; if less, the motion will be accelerated. We cannot enter here into the subject of Train Resistance. The total resistance to traction is made up of internal resistance due to the friction of the axles, and external resistances. The former forms a constant factor in the total train resistance; the latter constitute a variable one which increases, as far as the laws governing them have been determined, as the square of the speed. The external resistances are, the rolling friction of the wheels on the rails, the resistance of cars on a straight and level track, the resistance caused by gravity on ascending grades, the resistance due to the friction of the engine, the resistance of curves, the resistance of the atmosphere and that caused by the lateral play of the wheels and oscillations of the engine. The conditions affecting these are, the condition of the engine, and of the permanent way, the straightness of the track, curves, grades, the weather and wind. Perhaps there is no subject upon which engineering authorities differ more widely than upon the resistance of trains at different speeds. In fact they have never been determined except approximately and the English formulae do not represent the conditions upon American Roads. The formula for a straight and level track is based upon one of D. K. Clark's however. The fact that he ascertained was that the resistance to a train at 60 miles per hour was 21 lbs. per ton of train. Hence for any other velocity we should have $R : R' = v^2 : v'^2$ whence $R = \frac{R'}{v'^2}v^2 = \frac{21}{(60)^2} = \frac{v^2}{171}$. The constant resistance for American cars Mr. Forney takes at 6 lbs. per ton so that the resistance of this train would be represented by $R = 6 + \frac{v^2}{171} = 6 + \frac{(30)^2}{171} = 6. + 5.2 = 11.2$ lbs. per ton, or in all, 11.2 × 205 tons = $\underline{2,296.}$ lbs. In order to find the resistance of the engine and tender alone, the method given by Weissenborn's Engineering is to find the resistance of the locomotive as a carriage by means of the formula $R' = 6 + \frac{V^2}{240}$, which gives 9.7 lbs. per ton, or 494.7 lbs. total; and add to it what he calls the "Machinery Friction", which is estimated to follow the formula $F = \left(2 + \frac{V^2}{600}\right) \times \frac{W+w}{W}$, in which W is the weight of the engine and tender, and w, the gross weight of the train. This gives for the machinery friction $F = \left(2 + \frac{(30)^2}{600}\right) \times \frac{205}{51} = 3.5 \times 4. = 14$ lbs per ton, or in all, $51 \times 14. = 714$ lbs. The resistance of the engine alone would therefore be $494.7 + 714. = 1208.7$ lbs, to be constantly overcome at 30 miles per hour.

The resistance of the atmosphere also varies as the square of the speed. The train displaces a volume of air somewhat wider than the cars, which it carries along with it, and which causes an additional resistance by its friction against the surface of the ground. On this day, also, the wind was 36 miles an hour in velocity and almost dead against the train.* The following are the directions and velocities of the wind during the three days in on which the data were taken, which I have obtained from the Weather Signal Office, in Boston.

Record of Wind.

Day, - Wednesday, Mar. 15th; General direction W; Velocity, at 11.30 A.M., 36 miles per hour; at 12.35 P.M, 48 m.p.h.

" - Thursday, Mar. 16; Direction - Veered to E at 9.40 A.M;

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* The road was perfectly straight for 4 miles, practically level, and much exposed to the force of the wind. It extended over the Lynn marshes.

– Efficiency of the Mechanism. –

Velocity, at 11. A.M, at Boston, 20 miles per hour; 3 hrs" day night, at midnight, 30 m.p.h.

" Friday, Mar, 17th; Direction, wind continued E till Friday noon; Velocity, at 11. A.M. a maximum, 24 miles per hour; when the direction changed to N.E, and at 12.43 P.M. to N.W. The resistance of the Atmosphere, Wind and curves under 1 mile radius are usually taken together and allowed for in the formula. Mr. Zerah Colburn in 'Locomotive Engineering' estimates that these increase the resistance one half, or 50%. Applying this correction we find for the total resistance overcome by this engine, reduced to the rail, <u>3,444</u> lbs.

The efficiency of the Mechanism can now be found.

The <u>Efficiency</u> of the <u>Engine</u> or <u>Mechanism</u> = $\frac{\text{Useful Work}}{\text{Useful Work} + \text{the Lost Work}}$, or it is the ratio of the useful resistance overcome to the total energy exerted by the fluid on the piston. It is the product of the efficiencies of the pieces which transmit the power, and if the discussion of these parts of the engine had been taken up, it might be so found, by reducing the resistance over come by each, to the driving point, or piston, by means of the principle of virtual velocities. The formula for the efficiency of the Mechanism as a whole, was originally proposed by the Count de Pambour, and is given by Rankine as follows;— $\frac{R_1 \text{ ('Useful Load')}}{R \text{ (Total Resistance reduced to Piston)}} = \frac{R_1}{(1+f)R_1 + R_0} = \frac{1}{1+f+\frac{R_0}{R_1}}$. The total resistance, R, consists of a constant part R_0, which is the resistance unloaded, and a part increasing as the useful load R_1. Now the unloaded resistance, R_0, in the best engines is on an average, 1 lb. per sq. inch of piston, or $R_0 = 1\text{lb} \times A \times 2 = 1 \times 201 \text{sq}'' \times 2 = 402$ lbs. upon the two pistons. The value of the coeff. f, the Comte de Pambour takes at $\frac{1}{7} = .143$. Now, if we take the useful load as the resistance overcome in moving the train at 30 miles per hour, or $R_1' = T = \frac{4pAs}{\pi D} = 3{,}444$ lbs., and reduce it to the piston we obtain $2pA = \frac{R_1 \times \pi D}{2s} = \frac{3{,}444 \times 16.36}{4'} = 11{,}585.9$ lbs., and $\frac{R_0}{R_1} = \frac{2A}{2pA} = \frac{402}{11{,}585.9} = .0347$. The efficiency of the Mechanism is accordingly $\frac{R_1}{R} = \frac{1}{1.143 + .0347} = .85$ or <u>85%</u>.* But this appears to be too high. From the speed and pressure given, the tractive power of 5671 lbs. which we found must have balanced the resistances, and not have exceeded them as the condition of uniform speed. Hence, if we take the resistance at 5671 lbs. at the circumference of the driving wheels, in the same manner as above we find the effective pressure upon the pistons to be 23,194 lbs, the effective energy exerted per revolution, 92,777.56 foot-pounds and the efficiency <u>80%</u>.

But we may calculate it by yet another method. The

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* From experiments by Mr. Wm. Moore and others, the friction of the pistons alone was estimated at one-tenth the effective pressure, or 10% This is stated by Rankine, Mach. and Millwork, p 399, & 405.

tractive power exerted was, 5,671 lbs., the power consumed in overcoming the machinery friction, reduced to the rail we have found to be 714 lbs. The efficiency of the mechanism is therefore $\frac{5,671-714}{5,671}$, which gives 87%.

We have now completed what we have to say upon certain points in locomotive engineering. We have endeavored to present, not a finished essay upon the subject, but, perhaps, the less interesting results of the study and time devoted to it. Nothing has been said upon those great branches of Locomotive Engineering, the Permanent Way, Railway Plant, Watering stations, and shops, surveys and location of road, bed and ballasting, masonry, tunnelling, the superstructure, rolling stock or Railway Management. Nor upon the construction of locomotives in the workshop, and their draughting. We have taken simply a single example of the finished product of our New England Locomotive Establishments and applied to it some of the principles we have been studying during our four years course. The fundamental ways by which a complete knowledge of the engine is to be found are two.* I. The Action of the machine during parts of its period or cycle, by which we ascertain the laws which determine the inter-

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*Rankine.

—Summation of Efficiencies.—

nal efficiency of its parts, and which we have been obliged to omit. And, II, its action during whole periods, or the relation between mean efforts and mean resistances by which the actual efficiency is determined. To review, we have found the efficiency of the apparatus by which a portion of the energy in the coal is transferred to the working fluid. Next, the efficiency of this fluid has been ascertained. And, finally, the efficiency of the mechanism by which the portion of the energy utilized in the ~~former~~ latter, has been finally given out as useful work at the circumference of the wheels. The efficiency of the locomotive is therefore the product of the three factors found, and is as follows;—

1°. Efficiency of Furnace and Boiler, --(p.104)----.557.
2d. " " Steam, -----------(p.67)----.071*.
3d. " " Engine or Mechanism (p.161)----.80.

Efficiency of the Locomotive Engine, $.557 \times .071 \times .8 = \underline{.0316}$, or $\underline{3\frac{2}{10}}\%$.

Of the power in the coal, ninety-six and eight-tenths per cent is lost. Of the 10,316,236 foot-pounds in each pound of coal, but <u>339,120</u> are utilized. For every ton of coal, costing \$6.00 per ton, $19\frac{2}{10}$ cents are usefully invested and \$5.80 8/10, ~~thrown away~~ ineffectually applied. Of this, however, very nearly 70% is lost by reason of natural conditions beyond our control.+

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* The efficiency is practically but little increased by the expansion.

\+ Next page.

— Projects of Improvement in the Boiler, the Mechanism and Steam. —

The projects by which the Locomotive engine is to be improved relate to nearly all its parts. The boiler is an extremely wasteful piece of apparatus. Its efficiency will be increased when high pressures can be used (such as 200lbs to 400lbs per sq. inch), which depends upon the introduction of seamless steel boilers, and when fuel shall have become more expensive, doubtless eventually other means will be employed for the production of power. The defect in the use of steam seems to be radical and it is ventured to think that its use will sometime be abandoned. Although the theoretic superiority of air as the absorbing and transmitting fluid can be easily shown,* and engines have been constructed, the difficulties that stand in the way of their construction, their complexity, have as yet prevented them from exhibiting any actual superiority to the steam engine in its usual form.

In the mechanism, it seems as if the limit of improvement had nearly been reached. The beauty and simplicity of the Stephenson link, the crank and its connections leaves nothing to be desired. The various forms of rotary engines have all disappeared

+ Scientific American, Jan 11,-1873.-Art. 'Losses of Power in the Steam Engine.'

* Bourne's Treatise.

before it. It is undoubtedly the case, however, that the action of the valves are imperfect, and improvements are constantly being made, such as the Roberts "Central Exhaust." Outside of these questions lies that of gauge. The resistances to be overcome and the expense of locomotive power, and permanent way, has been found to vary nearly as the gauge. To quote from the last Annual Report of the Board of Railroad Commissioners, the average cost of roads of the standard gauge exclusive of equipment was $57,307.64 per mile and for the Narrow Gauge, $16,640.07, and the proportion of equipment $7,777.47 to $3,592.32. It was the intention to obtain data, similar to that which has been given from one of our Narrow Gauge Roads, the "Boston, Revere Beach and Lynn" R.R. These roads, having the United States Standard Gauge of 3 feet, are rapidly being opened in our State, and to them we look for cheap passenger transportation, rapid speed and economical working.

Boston, May 1st,
1876.

~The End.~