TABLES AND DIAGRAMS

RELATING TO

NON-CONDENSING

ENGINES & BOILERS

W. P. TROWBRIDGE.

NEW YORK:
JOHN WILEY & SON,
15 ASTOR PLACE.

1872.

INTRODUCTORY NOTE.

This collection of tables for non-condensing engines and boilers, and also the explanations relating to them, including those which refer to Horse Power of Engines, and the Diagrams showing the quantity of water required per horse power per hour for different degrees of expansion, was originally prepared at the Novelty Iron Works, New York, as a basis for the manufacture and sale of engines.

The explanatory note relating to the Horse Power of Engines was prepared by Mr. Horatio Allen, President of the Novelty Iron Works.

The explanations in regard to the tables of engines and boilers were prepared by Mr. C. E. Emery, who made, for the Novelty Iron Works, the valuable experiments which formed the basis of the tables.

The description of the manner in which the experiments were conducted is given by Mr. Emery, in a note accompanying the diagrams; and the computations of the tables were also made by him.

It was intended to publish the results of the experiments and the resulting tables in connection with the sale of engines, but the resolution of the proprietors of the Novelty Iron Works to close the works, made it necessary to withhold the matter from publication, notwithstanding it had been put into printed form.

Believing that the information obtained and set forth in a manner so readily comprehended and applicable, may be valuable for reference to all who wish to manufacture or employ the non-condensing steam engine, I procured the matter already printed, with a view of publishing it in the form in which it is here presented.

This explanation is rendered necessary on account of the references to the Novelty Iron Works which occur in the headings, and in other parts of the text.

I have added notes and tables on the horse powers of boilers, and on boiler-explosions and safety valves, subjects connected practically with the manufacture and management of boilers, but which were not included in the original design of the publication by the Novelty Iron Works.

The practical value of this extended list of engines and boilers to those who wish to purchase or manufacture engines for special purposes consists in this, that for a range of 5 to 300 horse power, a choice is offered of various dimensions of engines, speeds of revolution and pressures of steam; and for each engine in the list, the quantity of water, or steam, per hour which this engine will require is given. The list of boilers, on the other hand, furnishes the means of selecting the boiler or boilers of the principal types necessary to produce this steam.

Moreover, the diagrams showing the expenditure of steam or water per horse power per hour, for any degree of expansion in any particular engine with a given pressure, furnish a ready means of comparing the performance of such engine with a perfect standard.

The question of the limit of economy of expansion is here thoroughly and practically settled; and the results, as was to be anticipated, confirm the deductions of theory.

The tables possess, therefore, a special interest, not only in their practical applications, but also in connection with corresponding theoretical deductions.

W. P. TROWBRIDGE,

Professor of Dynamic Engineering.

Sheffield Scientific School, Yale College, April 5, 1872.

Horse Power of Steam Engines.

THE power which a Steam Engine can furnish is generally expressed in "Horse Power." It will therefore be of interest to most purchasers, and of special value to many, to have briefly stated, what is meant by a "Horse Power," and how it has happened that the power of a Steam Engine is thus expressed in reference to that of Horses.

Prior to the introduction of the Steam Engine, horses were very generally used to furnish power to perform various kinds of work, and especially the work of pumping water out of mines, raising coal, etc. For such purposes several horses working together were required. Thus, to work the pumps of a certain mine, five, six, seven or some other number of horses were found necessary. When it was proposed to substitute the new power of steam, the proposal naturally took the form of furnishing a Steam Engine capable of doing the work of the number of horses used at the same time. Hence, naturally followed the usage of stating the number of horses which a particular engine was equal to, that is, its "Horse Power."

But as the two powers were only alike in their equal capacity to do the same work it became necessary to refer in both powers to some work of a similar character which could be made the basis of comparison. Of this character was the work of raising a weight perpendicularly.

A certain number of horses could raise a certain weight, as of coal, out of a coal mine, at a certain speed; a Steam Engine, of certain dimensions and supply of steam, could raise the same weight at the same speed. Thus, the weight raised at a known speed could be made the common measure of the two powers. To use this common measure it was necessary to know what was the power of one horse in raising a weight at a known speed.

By observation and experiment it was ascertained that, referring to the average of horses, the most advantageous speed for work was at the rate of two-and-a-half miles per hour—that, at that rate, he could work eight hours per day raising, perpendicularly, from 100 to 150 lbs. The higher of these weights was taken by Watt, that is, 150 lbs. at 2½ miles per hour. But this fact can be expressed in another form: 2½ miles per hour is 220 feet per minute $\left(\frac{2\frac{1}{2} \times 5280}{60} = 220\right)$. So, the power of a horse was taken at 150 lbs., raised perpendicularly, at the rate of 220 feet per minute. This also can be expressed in another form: The same power which will raise 150 lbs. 220 feet high each minute, will raise

300 lbs.	110	feet high each minute.
3,000 lbs.	11	" "
33,000 lbs.	1	" "

For in each case the total work done is the same, viz.: same number of pounds raised one foot in one minute.

If it is clearly perceived that 33,000 lbs., raised at the rate of one foot high in a minute, is the equivalent of 150 lbs., at the rate of 220 feet per minute (or 2½ miles per hour), it will be fully understood how it is that 33,000 lbs., raised at the rate of one foot per minute expresses the power of one horse, and has been taken as the standard measure of power.

It has thus happened that the mode of designating the power of a Steam Engine has been by "Horse Power," and that one horse power, expressed in pounds raised, is a power that raises 33,000 lbs. one foot each minute. This unit of power is now universally received. Having a Horse Power expressed in pounds raised, it was easy to state the power of a Steam Engine in Horse Power, which was done in the following manner:

The force with which steam acts is usually expressed in its pressure in pounds on each square inch. The Piston of a High Pressure Steam Engine is under the action of the pressure of steam from the boiler, on one side of the piston, and of the back action of the pressure due to the discharging steam, on the other side. The difference between the two pressures is the effective pressure on the piston, and the power developed by the motion of the piston, under this pressure, will be according to the number of square inches acted on, and the speed per minute with which the piston is assumed to move. Thus, let the number of square inches in surface of piston of a steam engine be 100, and the *effective* pressure on each square inch be 33 lbs., and the movement of piston be at the rate of 200 feet per minute, then the total effective pressure on the piston will be $100 \times 33 = 3{,}300$ lbs., and the movement being 200 feet per minute, the piston will move with a power equal to raising 660,000 lbs., one foot high each minute (as $3{,}300 \times 200$ is 660,000), and as each 33,000 lbs., raised one foot high, is one horse power and $\frac{660000}{33000}$ is 20, then the power of this Engine is 20 Horse Power. If this power is used to do work, a part of it will be expended in overcoming the friction of the parts of the engine and of the machinery through which the power is transmitted to perform the work. The calculation made refers to the total power developed by the movement of the piston under the pressure of steam.

The number of feet moved by the piston each minute is known from the length of stroke of piston in feet, and number of revolutions of engine per minute, there being two strokes of the piston for each revolution of the engine. When these three facts are known the power of an engine can be readily and accurately ascertained, and it is evident that, without the knowledge of each of the facts, viz.: square inches of piston, effective pressure on each square inch, and movement of piston per minute, the power cannot be known.

But circumstances, especially those existing when the Condensing Engine was introduced by Watt, led to assumptions as to pressure per square inch and speed of piston, which, though true at the time, have long since ceased to be true, and consequently the rules based on such assumptions are entirely inapplicable, and when used must of necessity give false statements. As, however, such rules are still in use, although with the precautionary and unsatisfactory designation of *nominal* power, it is necessary to state what Nominal Horse Power is. In the United States the designation of Nominal Horse Power for Condensing Engines is seldom used, but in England the usage still prevails.

After Watt had introduced the Condensing Engine, he gave convenient rules for determining the power of his engines, and as, at that time, the steam pressure and piston speed in general use were very low, his rule was based on the assumption that, in all steam engines, the effective pressure was 7 lbs. per square inch, and that the speed of the piston varied with the length of stroke from 160 feet per minute for 2 feet stroke to 256 feet per minute for 8 feet stroke. The only facts necessary to obtain were the diameter of cylinder and length of stroke. The nominal power was then determined by Watts' rule, which is as follows:

Rule.—*Multiply the square of the diameter of the cylinder in inches by the cube root of the stroke in feet, and divide the product by* 47. *The quotient is the nominal horse power of the Engine.*

For many years, and especially in the United States, this rule has ceased to be of any value. This becomes plainly the case when, instead of 7 lbs. per square inch, the pressure actually used greatly exceeds 7, being from 20 to 50 and over, while the speed of piston is often from 400 to 700 feet per minute.

Some modifications of this rule have been made, but it is plain that when the pressure of steam and speed of piston are so various as at present it is simply not possible to have a general rule. If it becomes necessary to state the power of an engine, then the three facts named above, viz.: number of square inches of piston, effective pressure per square inch per stroke of piston, and speed of piston must be known or assumed, and when known or assumed the Horse Power can in that case be ascertained, as explained above.

In the United States, it is still usual to assign a certain Horse Power, often called "Rated Horse Power," for High Pressure Engines of certain dimensions, thus a cylinder of 12 inches diameter, 3 feet stroke is often called 20 horse power, and so of other dimensions.

The considerations already presented show that it is plainly impossible to say what horse power a 12 inch diameter, 3 feet stroke cylinder is, unless there is also stated what effective pressure on the piston, and speed of piston are to be used.

At what steam pressure that Engine will be used, and with what speed of piston run, remains to be decided, and until they are decided nothing can be said as to the power of the Engine. As it would not be safe to subject the Engine to higher steam than that for which it was built, nor to run it at higher speed than it is known its moving surface, in contact will bear, the *maximum* capacity of an Engine can be stated, within which the power of that Engine will be determined by the pressure and speed actually used.

Explanation of the Tables.

The tables commencing at page 7 show "*The sizes of the Non-Condensing, Stationary Steam Engines, built at the Novelty Iron Works, New York; and the Revolutions, Steam Pressures and Points of Cut-off which will produce the several Horse Powers named; also the Amount of Water used per Hour and Cost of the Power per Year, for each case.*"

Non-Condensing Engines, or, as they are often incorrectly called, *High Pressure Engines*, are those in which the steam, after its action on the piston, is permitted to escape into the atmosphere, and in which, therefore, the pressure of the outgoing steam must exceed the atmospheric pressure of fifteen pounds to the square inch.

There are two kinds of Horse Power referred to in the tables, viz.: The *Indicated Horse Power* and the *Net Horse Power*. The Indicated Horse Power is obtained by multiplying together the mean effective pressure in the cylinder, in pounds per square inch, the area of the piston in square inches, and the speed of piston, in feet per minute, and dividing the product by 33,000; and as the effective pressure on the piston is measured by an instrument called the Indicator, the power calculated therefrom is called the *Indicated* Horse Power. The *Net* Horse Power is the power available for useful work, and may be determined by subtracting, from the Indicated Horse Power, the power required to overcome the friction of the engine, when in the performance of its regular duty. For instance, if a person desires an engine to drive ten machines, each requiring ten Horse Power, the engine should be of sufficient size to furnish one hundred *Net* Horse Power; but to produce this would require about one hundred and fifteen *Indicated* Horse Power.

We manufacture two classes of engines, designated in the tables as "*Long Stroke Engines*" and "*Short Stroke Engines.*" These engines, as suggested by their names, have different proportions of stroke to diameter, and the shorter strokes are made with increased size of brasses and other modifications of detail which fit them for high speeds.

Column A of the tables shows the "*Net Horse Power,*" which has been calculated for the various powers usually required between 5 and 350 Horse Power. Each Horse Power can be obtained in a variety of ways, shown by the adjacent columns. The *Net* Horse Powers shown in the tables were obtained from the estimated Indicated Horse Powers, by deducting liberal allowances for friction. In the calculations, it was assumed that the short stroke engines have more friction than the long stroke.

Column B shows the "*Steam Pressures*" above the atmosphere assumed for each case. The calculations have been made for pressures of 60, 80 and 100 lbs., as being those in most general use, in non-condensing engines.

Column C shows the "*Point of Cut-off*" for each case. The table gives the results when the steam is cut off at $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ of the stroke from the beginning, which means that the full pressure of the steam has been allowed to act on the piston during $\frac{1}{4}$, $\frac{1}{2}$ or $\frac{3}{4}$ of the stroke, and that the remainder of the stroke, in each case, has been completed by the expansion of the steam.

Column D, in each class of engine, shows the "*Size and Designation*" of the engine. For instance, the expression 5×12 means that the piston is five inches in diameter and twelve inches stroke, and that the engine is designated or called a **"5 by 12 Engine,"** instead of a five Horse Power Engine, for reasons before stated.

Column E shows, for each class of engine, the "*Revolutions per Minute*" at which the several engines must be run, in order to produce the Net Horse Powers named, at the steam pressures and points of cut-off shown.

Columns F and F show the number of pounds of "*Water,*" evaporated into steam, required "*per Indicated Horse Power per hour,*" for each case. The facts were obtained from experiments which are hereinafter explained and illustrated. This column shows the comparative economy of the different methods of producing the power, and from it may readily be calculated the amount of coal required per Indicated Horse Power per hour.

Columns G and G show the "*Total Amount of Water per hour,*" in pounds, necessary to be evaporated to produce the Net Horse Power named. The results are calculated from the quantities in line F, due allowance being made for the difference between the Indicated and Net Horse Power. This column shows the evaporative power of the boiler required for each case.

Columns H and I show, for each class of engine, the "*Cost per Year of the Net Horse Power named.*" Column H shows the cost of the coal for one year, on the supposition that the engine runs ten hours per day, for 300 days in the year; that the coal, including cost of handling, etc., costs $8.00 per ton of 2,000 lbs., and that each pound of coal evaporates eight pounds of water. Variations may be made, by simple calculations, when the price of coal or the evaporation differs from the assumption. The quantities in column I were obtained by adding to the cost of the coal, in each case, the interest at ten per cent, on the estimated cost of the engine. This column shows, then, the total cost of the power per year for fuel and interest.

These tables and diagrams are based chiefly on experiments made for the Novelty Iron Works, under the direction of Mr. Charles E. Emery, formerly of the U. S. Naval Engineers, with machinery constructed especially for the purpose. Confirmatory results were, however, derived from the previous practice of that and other establishments, and from experiments made for the U. S. Navy, and under Government Commissioners. It had been shown conclusively that the attempt to make a complete series of experiments, under the many changes of condition necessary to a complete investigation, with *large* engines involved an incredible amount of labor and expense, and would occupy a period of time almost proscriptive. It was found, however, that by exercising care in the construction and operation of a *small* engine the results would show the laws applicable to engines of all sizes, and the apparatus could be at all times under the direction of the same persons, and thus secure great uniformity of observation.

The steam cylinder of the engine constructed for the experiments referred to herein was eight inches in diameter, and had eight inches stroke of piston. The power was applied to give motion to a large fan-blower, the speed of the engine being regulated by a gate in the discharge orifice of the blower. Steam was supplied from a locomotive boiler with a high steam drum, and the steam pipes and cylinders were carefully fitted. The bed plate of the cylinder formed a surface condenser, to which was connected an efficient air-pump operated from the engine crosshead. The cylinder ports were of ample area, and the cut-off was performed by plates having a 9-inch movement over the back of the main valve. The *Power* was measured with a Richards' Steam Engine Indicator, used in connection with a clock and engine register.

The *cost of the Power* was ascertained by weighing the amount of water (condensed steam) delivered from the air pump. The valves and piston of the engine were by good workmanship and extended operation made perfectly tight, under the maximum pressure used, and examinations were frequently made to prevent the possibility of steam or water leaks. During the experiments herein referred to air was let into the condenser to destroy the vacuum.

During each experiment the steam pressure and revolutions were kept exactly uniform. Each experiment was started with everything in average working condition—the engine register being thrown in gear, and the vessel, to receive the water from the hot well, pushed under the delivery of the latter simultaneously, at an even minute, as shown by the second-hand of the clock. Exactly at the end of every hour, to the second, the position of the engine register was noted, the water vessels shifted, and the one removed weighed on a platform scale.

This method of working insured such remarkable correspondence in the results that it was found possible to reduce the duration of many of the experiments to a single hour each. After each experiment some condition,—for instance, the point of cut-off,—was slightly changed, and another experiment started immediately after. This operation was continued, and the power and its cost calculated for each instance, when the results were dotted in proper position on a ruled sheet, and with the points as a guide, curves were drawn similar to those shown on page 23. In this way the modification of result due to changing the three first conditions mentioned on page 24 were obtained, viz., 1st, "The steam pressure;" 2d, "The amount of expansion;" and 3d, "The speed of revolution." The modification due to—4th—"The size of cylinders," was approximated by comparing the results with those obtained from larger engines operated under similar conditions. The experimental results were checked again by calculating theoretical curves similar to G and H, page 23, for each steam pressure, in which all the conditions, including an allowance for the condensation due to the mechanical work done, were taken into consideration. All the results are in harmony, and furnish a reliable basis for the information herein contained.

The tables are not designed to show the *maximum* result possible under the conditions named, but such as should be expected in ordinary good practice.

The proper size of boiler of either of the different types mentioned required to evaporate a given quantity of water was determined in the different ways by different individuals—one collating the previous practice of the Novelty Iron Works and other establishments; the other comparing numerous experiments on the subject. The results agreed in a most satisfactory manner. The tables on this subject were, however, calculated with considerable allowance for difference in condition, fuel, and management; the necessity of which allowance will be appreciated by the practical engineer.

TABLES

SHOWING THE SIZES OF THE NON-CONDENSING

Stationary Steam Engines,

BUILT AT

THE NOVELTY IRON WORKS,

NEW YORK;

AND THE

Revolutions, Steam Pressures and Points of Cut-off,

WHICH WILL PRODUCE THE

SEVERAL HORSE POWERS NAMED;

ALSO THE

AMOUNT OF WATER USED PER HOUR AND COST OF THE POWER PER YEAR,

FOR EACH CASE.

A	B	C	D		E	F	G	H	I	D		E	F	G	H	I
	STEAM		LONG STROKE ENGINES							SHORT STROKE ENGINES						
			ENGINE			WATER		COST PER YEAR OF THE POWER NAMED		ENGINE			WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation: Diam. In.	Stroke In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation: Diam. In.	Stroke In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
5 H. P.	100	$\frac{1}{4}$ stroke	5	12	95	30.4	190	$285	$375	5	9	129	28.9	183	$275	$343
	100	$\frac{1}{4}$ "	6	16	50	32.9	206	309	409	6	9	90	30.3	192	288	363
	80	$\frac{1}{4}$ "	5	12	123	31.4	196	294	384	5	9	167	30.0	190	285	353
	80	$\frac{1}{4}$ "	6	16	64	34.4	215	323	423	6	9	116	31.5	199	299	374
	60	$\frac{1}{4}$ "	5	12	173	33.3	209	314	404	5	9	235	31.6	200	300	368
	60	$\frac{1}{4}$ "	6	16	91	36.6	216	324	424	6	9	163	33.2	210	315	390
	60	$\frac{1}{4}$ "	7	20	53	39.3	243	365	475	7	12	89	36.2	226	339	422
	100	$\frac{1}{2}$ stroke	5	12	65	37.6	235	$353	$443	5	9	87	35.9	227	$341	$409
	80	$\frac{1}{2}$ "	5	12	81	39.0	244	366	456	5	9	110	37.0	234	351	419
Continued on next page.	60	$\frac{1}{2}$ "	5	12	111	40.9	256	383	473	5	9	149	38.9	245	367	435

A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation (Diam. × Stroke) In. × In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8 00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation (Diam. × Stroke) In. × In	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
5 H. P. Concluded.	60	½ stroke	6×16	88	41.5	259	$389	$489	6× 9	104	40.7	258	$386	$461
	80	¾ stroke	5×12	71	45.4	284	$426	$511	5× 9	95	43.7	264	$396	$460
	60	¾ "	5×12	101	46.9	297	445	530	5× 9	128	45.5	288	432	496
	60	¾ "	6×16	50	51.4	321	482	577	6× 9	90	47.7	302	453	524
10 H. P.	100	¼ stroke	6×16	100	29.0	362	$544	$644	6× 9	179	26.7	338	$507	$582
	80	¼ "	6×16	128	30.2	377	566	666	6× 9	231	28.5	361	541	616
	80	¼ "	7×20	75	32.4	400	600	710	7×12	126	29.1	364	546	629
	80	¼ "	8×20	58	33.0	408	612	745	8×12	97	30.9	388	582	682
	60	¼ "	7×20	105	34.4	425	637	747	7×12	178	31.7	396	594	677
	60	¼ "	8×20	81	35.6	439	659	792	8×12	138	32.7	409	613	713
	60	¼ "	9×24	53	37.4	460	690	850	9×15	85	35.0	432	648	768
	100	½ stroke	5×12	129	33.4	417	$626	$716	5× 9	174	31.7	401	$602	$670
	100	½ "	6×16	68	35.8	448	672	772	6× 9	121	33.2	420	630	705
	80	½ "	5×12	162	34.4	430	645	735	5× 9	220	32.9	416	625	693
	80	½ "	6×16	85	37.2	465	698	798	6× 9	153	34.3	434	651	726
	60	½ "	6×16	116	39.4	492	739	839	6× 9	207	35.8	453	680	755
	60	½ "	7×20	67	42.2	520	780	890	7×12	113	39.1	489	733	816
	100	¾ stroke	5×12	113	39.7	496	$744	$829	5× 9	152	38.2	484	$726	$790
	100	¾ "	6×16	59	42.2	528	792	887	6× 9	106	39.5	500	750	821
	80	¾ "	5×12	142	40.9	511	767	852	5× 9	190	39.4	500	750	814
	80	¾ "	6×16	74	43.7	546	819	914	6× 9	132	40.8	516	775	846
	60	¾ "	6×16	100	45.9	574	860	955	6× 9	179	42.6	539	809	880
15 H. P.	100	¼ stroke	7×20	87	29.0	537	$806	$916	7×12	145	27.1	508	$762	$845
	100	¼ "	8×20	66	29.6	548	822	955	8×12	112	27.6	518	776	876
	80	¼ "	7×20	112	30.2	559	839	949	7×12	189	28.1	527	790	873
	80	¼ "	8×20	86	31.0	574	861	994	8×12	145	29.0	544	816	916
	80	¼ "	9×24	56	32.4	592	888	1048	9×15	90	30.6	567	851	971
	60	¼ "	7×20	158	32.1	594	891	1000	7×12	266	29.8	559	838	921
	60	¼ "	8×20	122	33.1	613	920	1053	8×12	207	30.6	574	861	961
	60	¼ "	9×24	79	34.9	638	958	1118	9×15	127	32.6	603	905	1025
	60	¼ "	10×24	64	35.6	652	979	1159	10×15	104	33.3	616	924	1104
	100	½ stroke	6×16	101	33.7	631	$948	$1048	6× 9	181	31.2	592	$888	$963
	100	½ "	7×20	58	35.7	660	990	1100	7×12	98	33.6	630	945	1028
	80	½ "	6×16	127	34.9	654	981	1081	6× 9	229	32.3	613	920	995
	80	½ "	7×20	74	37.1	687	1031	1141	7×12	129	34.4	645	968	1051
	60	½ "	7×20	100	39.3	728	1092	1202	7×12	169	36.3	681	1021	1104
Continued on next page.	60	½ "	8×20	77	40.4	747	1121	1254	8×12	129	37.5	703	1055	1155

A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut off	Size and Designation (Diam. In. × Stroke In)	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation (Diam. In. × Stroke In.)	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
15 H. P. Concluded.	100	¾ stroke	5×12	170	37.3	699	$1049	$1130	5×9	228	35.9	682	$1022	$1086
	100	¾ "	6×16	88	40.1	752	1128	1223	6×9	159	38.7	735	1102	1173
	80	¾ "	6×16	111	41.3	774	1161	1256	6×9	199	38.7	735	1102	1173
	80	¾ "	7×20	65	43.4	803	1205	1309	7×12	108	41.0	769	1153	1231
	60	¾ "	7×20	86	45.9	850	1275	1379	7×12	146	42.9	804	1206	1284
	60	¾ "	8×20	66	47.2	873	1310	1438	8×12	112	44.0	825	1238	1334
20 H. P.	100	¼ stroke	7×20	115	27.6	681	$1022	$1132	7×12	194	25.8	645	$968	$1051
	100	¼ "	8×20	88	28.3	699	1048	1181	8×12	149	26.7	668	1001	1101
	80	¼ "	8×20	114	29.7	733	1100	1233	8×12	193	27.8	695	1043	1143
	80	¼ "	9×24	74	31.1	759	1138	1298	9×15	120	29.2	721	1081	1201
	80	¼ "	10×24	60	31.6	771	1156	1336	10×15	98	29.9	748	1122	1257
	60	¼ "	9×24	105	33.1	807	1211	1371	9×15	169	31.1	768	1152	1272
	60	¼ "	10×24	85	34.0	829	1244	1424	10×15	138	31.8	785	1178	1313
	60	¼ "	11×30	56	35.8	863	1295	1495	11×18	94	33.4	815	1222	1372
	100	½ stroke	7×20	78	34.3	847	$1270	$1380	7×12	131	31.8	795	$1193	$1276
	100	½ "	8×20	60	36.3	896	1344	1477	8×12	101	32.8	820	1230	1330
	80	½ "	7×20	98	35.6	880	1319	1429	7×12	166	33.1	828	1241	1324
	80	½ "	8×20	75	36.3	896	1344	1477	8×12	128	33.9	848	1271	1371
	60	½ "	7×20	134	37.4	923	1385	1495	7×12	225	34.8	870	1305	1388
	60	½ "	8×20	102	38.5	951	1426	1559	8×12	173	35.7	893	1339	1439
	60	½ "	9×24	67	40.4	985	1481	1641	9×15	108	37.1	916	1374	1494
	100	¾ stroke	6×16	118	38.4	960	$1440	$1535	6×9	212	35.8	906	$1359	$1430
	100	¾ "	7×20	68	40.5	1000	1500	1604	7×12	116	38.2	955	1433	1511
	80	¾ "	7×20	86	41.9	1035	1552	1656	7×12	145	39.6	990	1485	1563
	80	¾ "	8×20	66	42.6	1052	1578	1733	8×12	111	40.4	1010	1515	1611
	60	¾ "	7×20	115	44.0	1086	1630	1734	7×12	195	41.1	1028	1542	1620
	60	¾ "	8×20	88	45.1	1113	1669	1797	8×12	149	42.2	1055	1583	1679
25 H. P.	100	¼ stroke	8×20	110	27.3	843	$1264	$1397	8×12	186	25.7	803	$1205	$1305
	100	¼ "	9×24	72	28.5	869	1304	1464	9×15	116	27.0	833	1260	1380
	80	¼ "	9×24	93	30.0	915	1373	1533	9×15	150	28.3	873	1310	1430
	80	¼ "	10×24	75	30.6	933	1399	1579	10×15	122	28.9	891	1336	1471
	60	¼ "	9×24	131	32.0	976	1464	1624	9×15	212	30.1	929	1394	1514
	60	¼ "	10×24	106	32.7	997	1496	1676	10×15	172	30.8	951	1427	1562
	60	¼ "	11×30	69	34.6	1048	1572	1772	11×18	117	32.2	982	1473	1623
	60	¼ "	12×30	58	35.0	1054	1581	1801	12×18	96	32.9	1027	1541	1706
	100	½ stroke	7×20	97	33.2	1025	$1537	$1647	7×12	164	30.5	953	$1430	$1513
	100	½ "	8×20	75	33.7	1041	1560	1693	8×12	126	31.6	988	1481	1581
	80	½ "	8×20	94	35.1	1083	1625	1758	8×12	160	32.8	1025	1538	1638

Continued on next page.

A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation (Diam. × Stroke, In. In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation (Diam. × Stroke, In. In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
25 H. P. Concluded.	80	½ stroke	9 × 24	61	36.6	1116	$1674	$1834	9 × 15	99	34.6	1068	$1602	$1722
	60	½ "	9 × 24	83	39.2	1195	1793	1953	9 × 15	135	36.6	1130	1694	1814
	60	½ "	10 × 24	67	39.8	1213	1820	2000	10 × 15	109	37.4	1154	1731	1866
	100	¾ stroke	7 × 20	85	39.4	1216	$1824	$1928	7 × 12	145	37 1	1159	$1739	$1817
	100	¾ "	8 × 20	65	39.9	1231	1847	1975	8 × 12	111	37.9	1184	1777	1873
	80	¾ "	7 × 20	107	40.6	1253	1880	1984	7 × 12	183	38.5	1203	1805	1883
	80	¾ "	8 × 20	82	41.4	1278	1917	2045	8 × 12	138	39.3	1228	1842	1938
	80	¾ "	9 × 24	53	42.9	1308	1962	2117	9 × 15	87	40.9	1262	1893	2009
	60	¾ "	8 × 20	110	43.7	1349	2023	2151	8 × 12	176	41.3	1291	1936	2032
	60	¾ "	9 × 24	72	45.4	1384	2076	2231	9 × 15	116	43.2	1333	2000	2116
30 H. P.	100	¼ stroke	9 × 24	86	27.9	1021	$1531	$1691	9 × 15	140	26.3	974	$1461	$1581
	100	¼ "	10 × 24	70	28.2	1032	1548	1728	10 × 15	113	26.8	993	1489	1624
	80	¼ "	10 × 24	90	29.8	1090	1635	1815	10 × 15	146	28.1	1041	1561	1696
	80	¼ "	11 × 30	59	31.1	1159	1739	1939	11 × 18	99	29.3	1065	1597	1747
	60	¼ "	11 × 30	83	33.7	1217	1825	2025	11 × 18	140	31.3	1145	1718	1768
	60	¼ "	12 × 30	70	34.0	1229	1843	2063	12 × 18	115	31.9	1167	1751	1916
	60	¼ "	13 × 36	49	35.3	1261	1891	2144	13 × 21	85	33.0	1193	1789	1979
	100	½ stroke	7 × 20	117	32.2	1193	$1789	$1899	7 × 12	197	29.4	1103	$1654	$1737
	100	½ "	8 × 20	89	32.8	1215	1822	1955	8 × 12	151	30.5	1144	1716	1816
	100	½ "	9 × 24	58	34.1	1246	1869	2029	9 × 15	94	32.5	1204	1806	1926
	80	½ "	8 × 20	113	34.2	1266	1900	2033	8 × 12	192	32.1	1204	1806	1906
	80	½ "	9 × 24	74	35.7	1306	1959	2119	9 × 15	119	33.8	1252	1878	1998
	80	½ "	10 × 24	60	36.2	1324	1986	2166	10 × 15	97	35.4	1311	1967	2102
	60	½ "	9 × 24	100	37.9	1387	2080	2240	9 × 15	162	35.6	1319	1978	2098
	60	½ "	10 × 24	81	38.8	1420	2129	2309	10 × 15	131	36.4	1348	2022	2157
	100	¾ stroke	7 × 20	102	38.4	1422	$2133	$2237	7 × 12	173	35.9	1346	$2019	$2097
	100	¾ "	8 × 20	78	39.2	1452	2178	2306	8 × 12	132	37.0	1388	2081	2177
	80	¾ "	8 × 20	98	40.6	1504	2256	2384	8 × 12	166	38.5	1444	2166	2262
	80	¾ "	9 × 24	63	42.0	1537	2305	2460	9 × 15	104	40.0	1481	2222	2338
	60	¾ "	9 × 24	86	44.4	1624	2436	2591	9 × 15	139	42.0	1556	2333	2449
	60	¾ "	10 × 24	70	45.0	1646	2469	2642	10 × 15	114	42.9	1589	2383	2513
40 H. P.	100	¼ stroke	10 × 24	93	27.2	1327	$1990	$2170	10 × 15	151	25.7	1269	$1904	$2039
	100	¼ "	11 × 30	61	28.4	1369	2053	2253	11 × 18	103	26.7	1302	1954	2104
	80	¼ "	11 × 30	79	29.9	1441	2161	2361	11 × 18	133	28.1	1371	2057	2207
	80	¼ "	12 × 30	66	30.3	1460	2190	2410	12 × 18	111	28.6	1395	2093	2258
	60	¼ "	11 × 30	111	32.2	1552	2328	2528	11 × 18	187	29.9	1459	2189	2339
	60	¼ "	12 × 30	93	32.6	1571	2357	2577	12 × 18	153	30.6	1493	2240	2405
	60	¼ "	13 × 36	65	33.8	1610	2414	2667	13 × 21	114	31.7	1528	2292	2482
	60	¼ "	14 × 36	56	34.2	1619	2428	2704	14 × 21	98	32.2	1552	2328	2535

Continued on next page.

	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation (Diam. × Stroke) In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation (Diam. × Stroke) In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
40 H. P. Concluded.	60	¼ stroke	15 × 36	49	34.7	1652	$2478	$2803	15 × 24	74	33.1	1595	$2393	$2637
	100	½ stroke	8 × 20	119	31.5	1556	$2333	$2466	8 × 12	201	29.2	1460	$2190	$2290
	100	½ "	9 × 24	78	33.0	1610	2415	2575	9 × 15	126	30.9	1526	2289	2409
	100	½ "	10 × 24	63	33.4	1622	2433	2613	10 × 15	102	31.6	1560	2341	2476
	80	½ "	9 × 24	98	34.3	1673	2510	2670	9 × 15	159	32.3	1595	2393	2513
	80	½ "	10 × 24	79	34.9	1702	2554	2734	10 × 15	129	33.0	1630	2444	2579
	60	½ "	11 × 30	70	39.0	1880	2819	3019	11 × 18	119	36.2	1766	2649	2799
	60	½ "	12 × 30	59	39.4	1899	2848	3068	12 × 18	100	37.0	1817	2726	2891
	100	¾ stroke	8 × 20	104	37.6	1857	$2786	$2914	8 × 12	176	35.6	1780	$2670	$2766
	100	¾ "	9 × 24	68	39.1	1907	2861	3016	9 × 15	110	37.2	1837	2756	2871
	80	¾ "	9 × 24	85	40.6	1980	2971	3126	9 × 15	138	38.8	1916	2874	2990
	80	¾ "	10 × 24	69	41.1	2005	3007	3180	10 × 15	112	39.4	1970	2956	3086
	60	¾ "	10 × 24	93	43.5	2122	3183	3356	10 × 15	151	41.2	2034	3051	3181
	60	¾ "	11 × 30	61	45.4	2188	3282	3475	11 × 18	102	42.8	2088	3132	3277
50 H. P.	100	¼ stroke	11 × 30	76	27.6	1663	$2494	$2694	11 × 18	128	25.9	1580	$2370	$2520
	100	¼ "	12 × 30	64	27.9	1681	2521	2741	12 × 18	108	26.3	1604	2405	2570
	80	¼ "	11 × 30	98	29.0	1747	2620	2820	11 × 18	166	27.3	1665	2498	2648
	80	¼ "	12 × 30	83	29.4	1771	2657	2877	12 × 18	139	27.7	1689	2534	2698
	80	¼ "	13 × 36	58	30.2	1798	2696	2949	13 × 21	100	28.6	1723	2584	2774
	80	¼ "	14 × 36	50	30.6	1821	2732	3008	14 × 21	86	29.1	1735	2603	2810
	60	¼ "	12 × 30	116	31.6	1904	2856	3076	12 × 18	191	29.7	1811	2717	2882
	60	¼ "	13 × 36	82	32.8	1952	2929	3182	13 × 21	142	30.7	1850	2775	2965
	60	¼ "	14 × 36	70	33.1	1970	2955	3231	14 × 21	122	31.1	1873	2810	3017
	60	¼ "	15 × 36	61	33.7	2006	3009	3334	15 × 24	93	32.0	1928	2892	3136
	60	¼ "	16 × 42	46	34.5	2029	3044	3389	16 × 24	80	32.5	1958	2917	3177
	60	¼ "	17 × 42	41	35.0	2059	3089	3464	17 × 30	57	33.6	2000	3000	3276
	100	½ stroke	9 × 24	97	31.7	1933	$2899	$3059	9 × 15	157	29.8	1840	$2759	$2879
	100	½ "	10 × 24	79	32.3	1970	2954	3134	10 × 15	127	30.5	1883	2724	2859
	80	½ "	10 × 24	99	33.9	2067	3101	3281	10 × 15	161	31.8	1963	2944	3079
	80	½ "	11 × 30	65	35.2	2120	3181	3381	11 × 18	109	33.2	2024	3037	3187
	80	½ "	12 × 30	54	35.8	2157	3236	3456	12 × 18	92	33.9	2067	3101	3266
	60	½ "	11 × 30	88	37.8	2227	3416	3616	11 × 18	149	35.1	2140	3210	3360
	60	½ "	12 × 30	74	38.3	2314	3472	3692	12 × 18	125	35.7	2177	3265	3430
	60	½ "	13 × 36	52	39.5	2351	3527	3780	13 × 21	90	37.2	2241	3361	3551
	100	¾ stroke	9 × 24	85	38.1	2323	$3485	$3640	9 × 15	138	36.1	2228	$3343	$3459
	100	¾ "	10 × 24	69	38.6	2354	3530	3703	10 × 15	111	36.9	2278	3417	3547

Continued on next page.

A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation — Diam. × Stroke (In. × In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation — Diam. × Stroke (In. × In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
50 H. P. Concluded.	80	¾ stroke	10 × 24	86	40.2	2451	$3677	$3850	10 × 15	140	38.3	2364	$3546	$3676
	80	¾ "	11 × 30	56	41.6	2506	3759	3952	11 × 18	95	39.6	2415	3622	3767
	60	¾ "	11 × 30	76	44.2	2663	3994	4187	11 × 18	128	41.4	2524	3787	3932
	60	¾ "	12 × 30	64	44.5	2681	4021	4233	12 × 18	108	42.2	2573	3859	4018
	60	¾ "	13 × 36	45	45.8	2727	4091	4336	13 × 21	78	43.6	2626	3939	4123
60 H. P.	100	¼ stroke	11 × 30	91	26.9	1945	$2917	$3117	11 × 18	154	25.4	1550	$2324	$2474
	100	¼ "	12 × 30	77	27.2	1966	2949	3169	12 × 18	129	25.7	1880	2821	2986
	100	¼ "	13 × 36	54	28.0	2000	3000	3253	13 × 21	93	26.6	1923	2885	3075
	80	¼ "	12 × 30	99	28.7	2075	3112	3332	12 × 18	167	27.0	1976	2964	3129
	80	¼ "	13 × 36	69	29.6	2114	3171	3424	13 × 21	121	27.9	2017	3025	3215
	80	¼ "	14 × 36	60	29.9	2136	3204	3480	14 × 21	104	28.1	2031	3047	3254
	80	¼ "	15 × 36	52	30.2	2157	3236	3561	15 × 24	79	29.0	2096	3144	3388
	60	¼ "	14 × 36	84	32.3	2307	3461	3737	14 × 21	146	30.3	2190	3285	3492
	60	¼ "	15 × 36	74	32.7	2336	3504	3829	15 × 24	112	31.1	2248	3372	3616
	60	¼ "	16 × 42	55	33.7	2379	3568	3913	16 × 24	97	31.7	2264	3396	3656
	60	¼ "	17 × 42	49	33.9	2392	3588	3963	17 × 30	68	32.8	2315	3473	3749
	100	½ stroke	10 × 24	94	31.6	2312	$3468	$3648	10 × 15	153	29.7	2200	$3300	$3435
	100	½ "	11 × 30	62	33.0	2386	3578	3778	11 × 18	104	30.9	2261	3391	3541
	80	½ "	11 × 30	78	34.5	2494	3741	3941	11 × 18	131	32.5	2378	3567	3717
	80	½ "	12 × 30	65	34.8	2516	3773	3993	12 × 18	111	33.0	2415	3622	3787
	60	½ "	12 × 30	89	37.2	2689	4034	4254	12 × 18	150	34.8	2546	3820	3985
	60	½ "	13 × 36	62	38.6	2757	4136	4389	13 × 21	108	36.2	2617	3925	4115
	60	½ "	14 × 36	55	38.8	2795	4193	4469	14 × 21	93	36.8	2662	3993	4200
	100	¾ stroke	9 × 24	102	37.1	2715	$4072	$4227	9 × 15	165	35.3	2615	$3922	$4038
	100	¾ "	10 × 24	83	37.8	2766	4149	4322	10 × 15	134	35.8	2652	3978	4108
	100	¾ "	11 × 30	54	39.1	2827	4241	4434	11 × 18	91	37.2	2722	4083	4228
	80	¾ "	10 × 24	104	39.3	2876	4313	4486	10 × 15	168	37.6	2785	4178	4308
	80	¾ "	11 × 30	68	40.7	2942	4413	4606	11 × 18	114	38.9	2846	4270	4415
	80	¾ "	12 × 30	57	41.1	2971	4457	4669	12 × 18	96	39.4	2883	4324	4483
	60	¾ "	11 × 30	91	43.2	3123	4684	4877	11 × 18	154	40.6	2971	4457	4602
	60	¾ "	12 × 30	77	43.5	3145	4717	4929	12 × 18	129	41.2	3015	4522	4681
	60	¾ "	13 × 36	54	44.8	3200	4800	5045	13 × 21	93	42.7	3087	4631	4815
70 H. P.	100	¼ stroke	12 × 30	89	26.7	2252	$3378	$3598	12 × 18	150	25.3	2160	$3240	$3405
	100	¼ "	13 × 36	63	27.5	2292	3437	3690	13 × 21	109	26.0	2193	3290	3480
	100	¼ "	14 × 36	54	27.7	2308	3462	3738	14 × 21	94	26.3	2218	3327	3534
	80	¼ "	13 × 36	81	29.0	2417	3625	3878	13 × 21	141	27.4	2311	3466	3656
	80	¼ "	14 × 36	70	29.3	2442	3662	3938	14 × 21	121	27.7	2336	3504	3711
	80	¼ "	15 × 36	61	29.6	2467	3700	4025	15 × 24	92	28.5	2404	3606	3850
	80	¼ "	16 × 42	45	30.4	2504	3755	4100	16 × 24	80	28.8	2400	3600	3860

Continued on next page.

A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
	STEAM		LONG STROKE ENGINES: ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		SHORT STROKE ENGINES: ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation (Diam. × Stroke, In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation (Diam. × Stroke, In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
70 H. P. Concluded.	60	¼ stroke	15 × 36	86	32.1	2675	$4013	$4338	15 × 24	130	30.5	2572	$3858	$4102
	60	¼ "	16 × 42	64	33.0	2717	4076	4421	16 × 24	114	31.0	2583	3875	4135
	60	¼ "	17 × 42	57	33.2	2734	4101	4476	17 × 30	79	32.2	2683	4025	4301
	60	¼ "	19 × 48	35	34.8	2832	4248	4674	19 × 30	64	32.7	2706	4059	4379
	100	½ stroke	11 × 30	72	32.1	2707	$4061	$4261	11 × 18	121	30.3	2587	$3880	$4030
	100	½ "	12 × 30	60	32.7	2758	4137	4357	12 × 18	102	30.7	2621	3931	4096
	80	½ "	11 × 30	91	33.8	2851	4276	4476	11 × 18	153	31.8	2714	4071	4221
	80	½ "	12 × 30	76	34.3	2893	4339	4559	12 × 18	129	32.4	2766	4149	4314
	80	½ "	13 × 36	53	35.1	2925	4388	4641	13 × 21	93	33.3	2808	4213	4403
	60	½ "	13 × 36	73	37.7	3142	4712	4965	13 × 21	126	35.2	2970	4455	4645
	60	½ "	14 × 36	63	38.0	3167	4750	5026	14 × 21	108	36.0	3036	4554	4761
	60	½ "	15 × 36	55	38.6	3217	4825	5150	15 × 24	83	37.0	3120	4680	4924
	60	½ "	16 × 42	40	39.7	3269	4904	5249	16 × 24	72	37.4	3140	4710	4970
	100	¾ stroke	10 × 24	96	37.1	3167	$4750	$4923	10 × 15	156	35.3	3051	$4576	$4706
	100	¾ "	11 × 30	63	38.4	3239	4858	5051	11 × 18	106	36.5	3116	4674	4819
	80	¾ "	11 × 30	79	40.1	3382	5073	5266	11 × 18	133	38.3	3270	4904	5049
	80	¾ "	12 × 30	66	40.5	3416	5123	5335	12 × 18	112	38.8	3312	4968	5127
	80	¾ "	13 × 36	46	41.4	3450	5175	5420	13 × 21	81	39.7	3342	5013	5197
	60	¾ "	12 × 30	89	42.8	3610	5414	5626	12 × 18	150	40.4	3449	5173	5332
	60	¾ "	13 × 36	63	44.0	3667	5500	5745	13 × 21	109	41.7	3517	5276	5460
	60	¾ "	14 × 36	54	44.4	3700	5550	5817	14 × 21	93	42.4	3576	5364	5564
80 H. P.	100	¼ stroke	13 × 36	72	27.0	2571	$3857	$4110	13 × 21	124	25.7	2477	$3716	$3906
	100	¼ "	14 × 36	62	27.2	2590	3886	4162	14 × 21	107	25.8	2488	3732	3939
	100	¼ "	15 × 36	54	27.5	2619	3929	4254	15 × 24	82	26.5	2554	3831	4075
	80	¼ "	14 × 36	80	28.8	2743	4114	4390	14 × 21	138	27.2	2622	3933	4140
	80	¼ "	15 × 36	70	29.1	2771	4157	4482	15 × 24	106	27.9	2689	4034	4278
	80	¼ "	16 × 42	52	29.8	2805	4207	4552	16 × 24	92	28.4	2705	4058	4318
	80	¼ "	17 × 42	46	30.0	2824	4235	4610	17 × 30	64	29.0	2762	4143	4419
	60	¼ "	16 × 42	73	32.5	3058	4588	4933	16 × 24	130	30.3	2886	4329	4589
	60	¼ "	17 × 42	65	32.6	3068	4602	4977	17 × 30	90	31.6	3009	4519	4795
	60	¼ "	19 × 48	45	33.8	3181	4772	5198	19 × 30	73	32.2	3030	4545	4865
	100	½ stroke	11 × 30	82	31.7	3055	$4583	$4783	11 × 18	138	29.7	2898	$4346	$4496
	100	½ "	12 × 30	69	32.1	3094	4641	4861	12 × 18	116	30.2	2946	4420	4584
	100	½ "	13 × 36	48	33.1	3152	4728	4981	13 × 21	84	31.3	3017	4525	4715
	80	½ "	12 × 30	87	33.7	3248	4872	5092	12 × 18	148	31.7	3093	4639	4804
	80	½ "	13 × 36	61	34.6	3295	4943	5196	13 × 21	106	32.7	3152	4728	4918
	80	½ "	14 × 36	53	34.9	3324	4986	5262	14 × 21	91	33.1	3190	4785	4992
	60	½ "	13 × 36	83	37.2	3543	5314	5567	13 × 21	144	34.7	3344	5016	5206
	60	½ "	14 × 36	71	37.5	3571	5357	5633	14 × 21	124	35.2	3393	5090	5297
	60	½ "	15 × 36	62	38.0	3619	5429	5754	15 × 24	95	36.2	3489	5234	5478

Continued on next page.

A	B	C	D		E	F	G	H	I	D		E	F	G	H	I
	STEAM		LONG STROKE ENGINES							SHORT STROKE ENGINES						
			ENGINE			WATER		COST PER YEAR OF THE POWER NAMED		ENGINE			WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation: Diam. (In.)	Stroke (In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation: Diam. (In.)	Stroke (In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
80 H. P. Concluded.	60	½ stroke	16 × 42		46	39.0	3671	$5506	$5851	16 × 24		82	36.8	3505	$5257	$5517
	60	½ "	17 × 42		41	39.2	3689	5534	5909	17 × 30		65	37.4	3657	5485	5761
	100	¾ stroke	11 × 30		72	37.8	3643	$5465	$5658	11 × 18		121	35.9	3502	$5254	$5399
	100	¾ "	12 × 30		60	38.3	3692	5537	5749	12 × 18		102	36.3	3541	5312	5471
	80	¾ "	12 × 30		76	40.0	3855	5783	5995	12 × 18		128	37.9	3698	5546	5705
	80	¾ "	13 × 36		53	40.8	3885	5829	6074	13 × 21		92	39.2	3774	5660	5844
	60	¾ "	13 × 36		72	43.3	4124	6186	6431	13 × 21		124	41.1	3962	5943	6127
	60	¾ "	14 × 36		62	43.7	4162	6243	6510	14 × 21		107	41.6	4009	6019	6219
	60	¾ "	15 × 36		54	44.2	4210	6314	6630	15 × 24		82	42.6	4106	6159	6396
90 H. P.	100	¼ stroke	13 × 36		81	26.7	2861	$4291	$4544	13 × 21		140	25.3	2743	$4115	$4305
	100	¼ "	14 × 36		69	26.8	2871	4307	4583	14 × 21		120	25.5	2765	4147	4354
	100	¼ "	15 × 36		61	27.1	2904	4355	4680	15 × 24		92	26.2	2841	4262	4506
	100	¼ "	16 × 42		45	27.7	2933	4399	4744	16 × 24		80	26.4	2829	4244	4504
	80	¼ "	15 × 36		78	28.8	3086	4629	4954	15 × 24		119	27.6	2993	4489	4733
	80	¼ "	16 × 42		58	29.4	3113	4670	5015	16 × 24		103	27.9	2989	4484	4744
	80	¼ "	17 × 42		52	29.6	3134	4701	5076	17 × 30		71	28.9	3097	4645	4921
	60	¼ "	16 × 42		82	31.9	3378	5067	5412	16 × 24		145	30.0	3214	4821	5081
	60	¼ "	17 × 42		73	32.2	3409	5114	5489	17 × 30		101	31.1	3334	5001	5277
	60	¼ "	19 × 48		50	33.4	3495	5243	5669	19 × 30		82	31.7	3354	5031	5351
	60	¼ "	21 × 48		44	33.4	3495	5243	5731	21 × 30		67	32.3	3420	5130	5496
	100	½ stroke	11 × 30		92	31.3	3394	$5091	$5291	11 × 18		155	29.2	3205	$4809	$4959
	100	½ "	12 × 30		78	31.6	3427	5140	5360	12 × 18		131	29.7	3260	4890	5055
	100	½ "	13 × 36		54	32.6	3493	5239	5492	13 × 21		94	30.9	3351	5026	5216
	80	½ "	12 × 30		98	33.2	3600	5400	5620	12 × 18		166	31.3	3435	5153	5318
	80	½ "	13 × 36		69	34.1	3654	5480	5733	13 × 21		119	32.4	3513	5270	5460
	80	½ "	14 × 36		59	34.4	3686	5529	5805	14 × 21		103	32.7	3546	5319	5526
	80	½ "	15 × 36		52	34.7	3718	5577	5902	15 × 24		78	33.7	3654	5481	5725
	60	½ "	14 × 36		80	36.9	3954	5930	6206	14 × 21		139	34.7	3763	5644	5851
	60	½ "	15 × 36		70	37.3	3996	5995	6320	15 × 24		106	35.6	3860	5790	6034
	60	½ "	16 × 42		52	38.4	4066	6109	6454	16 × 24		93	36.1	3868	5802	6062
	60	½ "	17 × 42		46	38.7	4098	6146	6521	17 × 30		64	37.5	4018	6027	6303
	100	¾ stroke	11 × 30		81	37.3	4045	$6067	$6260	11 × 18		136	35.5	3896	$5845	$5990
	100	¾ "	12 × 30		68	37 8	4099	6148	6360	12 × 18		114	35.9	3940	5910	6069
	100	¾ "	13 × 36		48	38.7	4146	6219	6464	13 × 21		83	37.0	4012	6018	6202
	80	¾ "	12 × 30		85	39.5	4283	6425	6637	12 × 18		144	37.7	4162	6243	6402
	80	¾ "	13 × 36		60	40.3	4318	6477	6722	13 × 21		104	38.6	4186	6278	6462
	80	¾ "	14 × 36		53	40.6	4350	6525	6792	14 × 21		89	39 0	4230	6345	6545
	60	¾ "	13 × 36		81	42.9	4596	6895	7140	13 × 21		140	40.4	4381	6572	6756
	60	¾ "	14 × 36		69	43.1	4618	6927	7194	14 × 21		120	41.0	4446	6669	6869
	60	¾ "	15 × 36		60	43.7	4682	7023	7339	15 × 24		92	42.0	4554	6831	7068
	60	¾ "	16 × 42		45	44.7	4733	7099	7434	16 × 24		80	42.5	4554	6831	7082

A	B	C	LONG STROKE ENGINES — ENGINE — D	E	WATER — F	G	COST PER YEAR OF THE POWER NAMED — H	I	SHORT STROKE ENGINES — ENGINE — D	E	WATER — F	G	COST PER YEAR OF THE POWER NAMED — H	I
NET HORSE POWER	STEAM — Pressure above Atmosphere in pounds per square inch	STEAM — Point of Cut-off	Size and Designation — Diam. × Stroke (In. × In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	Total Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)	Size and Designation — Diam. × Stroke (In. × In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	Total Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)
100 H. P.	100	¼ stroke	14 × 36	77	26.5	3014	$4521	$4797	14 × 21	134	25.2	3036	$4554	$4761
	100	¼ "	15 × 36	67	26.8	3190	4786	5111	15 × 24	102	25.8	3109	4663	4907
	100	¼ "	16 × 42	50	27.4	3224	4835	5180	16 × 24	88	26.1	3107	4660	4920
	100	¼ "	17 × 42	45	27.5	3235	4853	5228	17 × 30	61	26.9	3203	4804	5080
	80	¼ "	15 × 36	87	28.3	3370	5055	5380	15 × 24	132	27.2	3277	4916	5160
	80	¼ "	16 × 42	65	29.0	3424	5135	5480	16 × 24	115	27.5	3274	4911	5171
	80	¼ "	17 × 42	57	29.3	3488	5232	5607	17 × 30	79	28.5	3393	5089	5365
	80	¼ "	19 × 48	40	30.1	3500	5250	5676	19 × 30	64	28.9	3400	5100	5420
	60	¼ "	17 × 42	81	31.8	3741	5612	5987	17 × 30	112	30.7	3655	5482	5758
	60	¼ "	19 × 48	56	32.9	3826	5738	6164	19 × 30	91	31.2	3671	5506	5826
	60	¼ "	21 × 48	49	32.9	3826	5738	6226	21 × 30	74	31.9	3752	5628	5994
	60	¼ "	23 × 54	34	33.9	3897	5846	6396	23 × 36	51	32.8	3814	5721	6133
	100	½ stroke	12 × 36	86	31.3	3783	$5659	$5879	12 × 18	146	29.2	3561	$5342	$5507
	100	½ "	13 × 36	60	32.1	3822	5732	5985	13 × 21	105	30.2	3639	5458	5648
	100	½ "	14 × 36	52	32.2	3833	5750	6026	14 × 21	90	30.7	3700	5550	5757
	80	½ "	13 × 36	76	33.7	4012	6017	6270	13 × 21	132	32.0	3855	5783	5973
	80	½ "	14 × 36	66	34.1	4060	6080	6356	14 × 21	114	32.3	3892	5838	6045
	80	½ "	15 × 36	56	34.4	4095	6143	6468	15 × 24	87	33.1	3988	5982	6226
	80	½ "	16 × 42	48	34.6	4071	6107	6452	16 × 24	75	33.4	3979	5968	6228
	60	½ "	15 × 36	78	37.0	4405	6607	6932	15 × 24	118	35.1	4229	6343	6587
	60	½ "	16 × 42	58	37.8	4447	6671	7016	16 × 24	103	35.6	4238	6357	6617
	60	½ "	17 × 42	51	38.2	4494	6741	7116	17 × 30	71	37.1	4417	6625	6901
	100	¾ stroke	11 × 30	90	37.0	4458	$6687	$6880	11 × 18	151	35.0	4268	$6402	$6547
	100	¾ "	12 × 30	75	37.3	4494	6741	6953	12 × 18	127	35.5	4329	6494	6653
	100	¾ "	13 × 36	53	38.3	4560	6839	7084	13 × 21	92	36.5	4398	6596	6780
	80	¾ "	12 × 30	95	39.0	4699	7048	7260	12 × 18	160	37.3	4549	6824	6983
	80	¾ "	13 × 36	67	39.9	4750	7125	7370	13 × 21	115	38.3	4614	6922	7106
	80	¾ "	14 × 36	59	40.1	4774	7161	7428	14 × 21	97	38.7	4663	6994	7194
	80	¾ "	15 × 36	50	40.6	4883	7325	7641	15 × 24	76	39.4	4747	7120	7357
	60	¾ "	14 × 36	77	42.7	5083	7625	7892	14 × 21	134	40.4	4865	7297	7497
	60	¾ "	15 × 36	67	43.2	5142	7714	8030	15 × 24	102	41.3	4976	7464	7701
	60	¾ "	16 × 42	50	44.1	5188	7782	8117	16 × 24	88	42.0	5000	7500	7751
	60	¾ "	17 × 42	44	44.4	5224	7836	8201	17 × 30	61	43.4	5143	7715	7981
125 H. P.	100	¼ stroke	15 × 36	84	26.1	3908	$5862	$6187	15 × 24	128	25.1	3780	$5670	$5914
	100	¼ "	16 × 42	63	26.7	3926	5890	6235	16 × 24	111	25.4	3779	5668	5928
	100	¼ "	17 × 42	56	26.8	3941	5912	6287	17 × 30	77	26.2	3900	5850	6126
	80	¼ "	17 × 42	72	28.4	4176	6165	6540	17 × 30	99	27.7	4121	6182	6458
	80	¼ "	19 × 48	50	29.4	4273	6410	6836	19 × 30	80	28.1	4132	6198	6518
	80	¼ "	21 × 48	43	29.4	4273	6410	6898	21 × 30	66	28.6	4266	6309	6675
	60	¼ "	19 × 48	60	31.9	4637	6955	7381	19 × 30	113	30.4	4471	6706	7026
Continued on next page.	60	¼ "	21 × 48	61	32.1	4666	6999	7487	21 × 30	93	30.9	4545	6818	7184

A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation Diam. × Stroke (In. × In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	Total Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)	Size and Designation Diam. × Stroke (In. × In)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	Total Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)
125 H. P. Concluded.	60	¼ stroke	23 × 54	42	33.2	4770	$7155	$7705	23 × 36	64	31.9	4637	$6955	$7367
	60	¼ "	24 × 54	39	33.2	4770	7155	7770	24 × 36	59	32.0	4651	6977	7438
	100	½ stroke	13 × 36	76	31.3	4658	$6987	$7240	13 × 21	131	29.2	4398	$6596	$6786
	100	½ "	14 × 36	65	31.4	4673	7009	7285	14 × 21	113	29.7	4472	6708	6915
	100	½ "	15 × 36	57	31.7	4717	7076	7401	15 × 24	86	30.5	4593	6889	7133
	100	½ "	16 × 42	43	32.3	4739	7109	7454	16 × 24	77	30.7	4569	6853	7113
	80	½ "	14 × 36	82	33.1	4925	7388	7664	14 × 21	125	31.8	4789	7183	7390
	80	½ "	15 × 36	71	33.6	5000	7500	7825	15 × 24	109	32.3	4864	7296	7540
	80	½ "	16 × 42	53	34.3	5044	7566	7911	16 × 24	95	32.6	4851	7277	7537
	80	½ "	17 × 42	47	34.4	5059	7588	7963	17 × 30	65	33.6	5000	7500	7776
	60	½ "	16 × 42	73	36.9	5426	8140	8485	16 × 24	128	34.5	5169	7753	8013
	60	½ "	17 × 42	64	37.1	5456	8184	8559	17 × 30	89	36.0	5357	8036	8312
	60	½ "	19 × 48	45	38.3	5567	8350	8776	19 × 30	72	36.5	5368	8052	8372
	100	¾ stroke	12 × 30	94	36.5	5497	$8245	$8457	12 × 18	159	34.6	5274	$7911	$8070
	100	¾ "	13 × 36	66	37.3	5551	8326	8571	13 × 21	115	35.5	5346	8020	8204
	100	¾ "	14 × 36	57	37.6	5595	8393	8660	14 × 21	99	35.8	5392	8088	8288
	100	¾ "	15 × 36	50	37.8	5625	8438	8754	15 × 24	75	36.7	5525	8288	8525
	80	¾ "	13 × 36	84	39.1	5819	8729	8974	13 × 21	144	37.5	5648	8472	8656
	80	¾ "	14 × 36	73	39.4	5863	8795	9040	14 × 21	124	37.7	5677	8515	8715
	80	¾ "	15 × 36	62	39.8	5923	8884	9200	15 × 24	95	38.6	5813	8720	8957
	80	¾ "	16 × 42	47	40.4	5941	8912	9247	16 × 24	82	38.9	5790	8685	8936
	80	¾ "	17 × 42	41	40.6	5971	8957	9322	17 × 30	57	39.8	5923	8884	9150
	60	¾ "	15 × 36	84	42.1	6265	9397	9713	15 × 24	127	40.4	6080	9120	9357
	60	¾ "	16 × 42	63	43.1	6338	9507	9842	16 × 24	111	40.8	6072	9108	9359
	60	¾ "	17 × 42	55	43.4	6382	9574	9939	17 × 30	77	42.2	6280	9420	9686
150 H. P.	100	¼ stroke	16 × 42	75	26.2	4624	$6935	$7280	16 × 24	133	24.9	4446	$6670	$6930
	100	¼ "	17 × 42	67	26.3	4641	6962	7337	17 × 30	92	25.7	4590	6885	7161
	100	¼ "	19 × 48	46	26.9	4692	7038	7464	19 × 30	75	25.9	4571	6856	7176
	100	¼ "	21 × 48	40	27.1	4704	7055	7543	21 × 30	61	26.4	4659	6988	7354
	80	¼ "	19 × 48	60	28.7	5006	7509	7935	19 × 30	96	27.6	4871	7306	7626
	80	¼ "	21 × 48	52	28.9	5041	7561	8049	21 × 30	79	28.0	4941	7413	7779
	80	¼ "	23 × 54	36	29.6	5103	7655	8205	23 × 36	54	28.7	5006	7509	7921
	60	¼ "	21 × 48	73	31.4	5477	8216	8704	21 × 30	112	30.2	5330	7995	8361
	60	¼ "	23 × 54	50	32.6	5621	8431	8981	23 × 36	76	31.3	5469	8188	8600
	60	¼ "	24 × 54	46	32.7	5638	8457	9072	24 × 36	70	31.4	5477	8215	8676
	60	¼ "	26 × 54	40	32.7	5638	8457	9112	26 × 42	51	32.0	5581	8372	8863
	60	¼ "	27 × 60	33	33.1	5642	8463	9178	27 × 42	49	32.2	5552	8328	8864
	60	¼ "	28 × 60	30	33.3	5619	8429	9205	28 × 48	39	32.6	5621	8432	9014
	100	½ stroke	14 × 36	78	30.7	5482	$8223	$8499	14 × 21	135	28.9	5223	$7834	$8041
	100	½ "	15 × 36	68	31.0	5536	8304	8629	15 × 24	103	29.8	5409	8119	8363

Continued on next page.

A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation, Diam. × Stroke (In. × In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)	Size and Designation, Diam. × Stroke (In. × In.)	Revolutions per Minute	Per I. H. P. per Hour (Lbs.)	TOTAL Per Hour for Net Horse Power named (Lbs.)	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
150 H. P. Concluded.	100	½ stroke	16 × 42	51	31.7	5594	$8391	$8736	16 × 24	92	30.0	5357	$8035	$8295
	100	½ "	17 × 42	45	32.0	5647	8471	8846	17 × 30	68	30.7	5480	8220	8496
	80	½ "	15 × 36	85	32.8	5857	8786	9111	15 × 24	131	31.4	5675	8512	8756
	80	½ "	16 × 42	64	33.6	5929	8894	9239	16 × 24	114	32.0	5714	8571	8831
	80	½ "	17 × 42	57	33.8	5964	8947	9323	17 × 30	78	33.0	5893	8839	9115
	80	½ "	19 × 48	40	34.6	6035	9053	9479	19 × 30	63	33.3	5877	8815	9135
	60	½ "	17 × 42	77	36.1	6371	9556	9931	17 × 30	107	35.0	6250	9370	9646
	60	½ "	19 × 48	53	37.5	6541	9811	10237	19 × 30	75	36.3	6406	9609	9929
	60	½ "	21 × 48	46	37.8	6594	9891	10379	21 × 30	71	36.3	6406	9609	9975
	100	¾ stroke	13 × 36	79	36.7	6554	$9830	10075	13 × 21	138	34.9	6307	$9461	$9645
	100	¾ "	14 × 36	68	36.9	6589	9884	10151	14 × 21	118	35.3	6379	9568	9768
	100	¾ "	15 × 36	60	37.1	6625	9938	10254	15 × 24	91	35.9	6488	9732	9969
	100	¾ "	16 × 42	54	37.1	6547	9821	10156	16 × 24	78	36.3	6482	9723	9974
	80	¾ "	14 × 36	88	38.7	6911	10367	10634	14 × 21	149	37 0	6687	10030	10230
	80	¾ "	15 × 36	75	39.0	6964	10446	10762	15 × 24	114	37.9	6849	10273	10510
	80	¾ "	16 × 42	56	39.8	7107	10661	10996	16 × 24	98	38.3	6840	10260	10511
	80	¾ "	17 × 42	49	40.0	7143	10714	11079	17 × 30	68	39.2	7000	10500	10766
	60	¾ "	16 × 42	75	42.2	7536	11304	11639	16 × 24	133	40.0	7143	10814	11065
	60	¾ "	17 × 42	66	42.6	7607	11411	11776	17 × 30	92	41.4	7393	11089	11355
	60	¾ "	19 × 48	46	43.7	7712	11568	11982	19 × 30	75	41.9	7394	11091	11401
	60	¾ "	21 × 48	40	44.0	7765	11647	12122	21 × 30	61	42.8	7553	11330	11686
175 H. P.	100	¼ stroke	17 × 42	78	25.9	5332	$7999	$8374	17 × 30	107	25.2	5250	$7875	$8151
	100	¼ "	19 × 48	54	26.5	5392	8089	8515	19 × 30	87	25.6	5270	7905	8225
	100	¼ "	21 × 48	47	26.6	5413	8119	8607	21 × 30	71	26.0	5353	8029	8395
	80	¼ "	19 × 48	70	28.2	5738	8608	9034	19 × 30	113	27.1	5577	8365	8685
	80	¼ "	21 × 48	60	28.4	5779	8669	9157	21 × 30	92	27.8	5723	8584	8950
	80	¼ "	23 × 54	42	29.2	5874	8810	9360	23 × 36	63	28.2	5730	8595	9007
	80	¼ "	24 × 54	38	29.4	5914	8871	9486	24 × 36	58	28.4	5780	8670	9131
	60	¼ "	23 × 54	58	32.1	6457	9686	10236	23 × 36	89	30.7	6256	9384	9796
	60	¼ "	24 × 54	54	32.1	6457	9686	10301	24 × 36	82	30.9	6291	9436	9897
	60	¼ "	26 × 54	46	32.2	6477	9716	10371	26 × 42	60	31.4	6387	9581	10072
	60	¼ "	27 × 60	38	32.7	6503	9754	10469	27 × 42	55	31.7	6376	9565	10101
	60	¼ "	28 × 60	35	32.8	6523	9784	10560	28 × 48	45	32.2	6477	9716	10298
	60	¼ "	30 × 60	31	33.0	6563	9844	10684	30 × 48	40	32.4	6517	9776	10406
	100	½ stroke	15 × 36	79	30.4	6333	$9500	$9825	15 × 24	121	29.1	6135	$9203	$9447
	100	½ "	16 × 42	59	31.2	6424	9635	9980	16 × 24	108	29.4	6125	9187	9447
	100	½ "	17 × 42	52	31.4	6465	9697	10072	17 × 30	80	30.0	6250	9375	9651
	80	½ "	16 × 42	75	32.9	6774	10160	10505	16 × 24	132	31.3	6512	9768	10028
	80	½ "	17 × 42	66	33.2	6835	10253	10628	17 × 30	92	32.4	6750	10125	10401
	80	½ "	19 × 48	46	34.1	6939	10408	10834	19 × 30	74	32.8	6753	10129	10449
	80	½ "	21 × 48	40	34.2	6959	10439	10927	21 × 30	61	33.2	6835	10252	10618

Continued on next page.

	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation (Diam. × Stroke) In. × In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	Total Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)	Size and Designation (Diam. × Stroke) In. × In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	Total Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)
175 H. P. Concluded.	60	½ stroke	19×48	62	36.9	7509	$11263	$11689	19×30	142	33.7	6938	$10407	$10727
	60	½ "	21×48	54	37.0	7529	11294	11782	21×30	83	35.6	7330	10995	11361
	60	½ "	23×54	37	38.2	7684	11526	12076	23×36	56	36.8	7489	11233	11645
	60	½ "	24×54	34	38.3	7704	11556	12171	24×36	52	36.9	7509	11263	11724
	100	¾ stroke	14×36	80	36.2	7542	$11312	$11579	14×21	138	34.6	7271	$10906	$11106
	100	¾ "	15×36	70	36.5	7604	11406	11722	15×24	105	35.3	7442	11163	11400
	100	¾ "	16×42	63	36.7	7556	11334	11669	16×24	92	35.7	7437	11158	11409
	100	¾ "	17×42	46	37.4	7782	11674	12039	17×30	64	36.7	7646	11469	11735
	80	¾ "	15×36	87	38.5	8021	12031	12347	15×24	133	37.3	7864	11796	12033
	80	¾ "	16×42	65	39.2	8071	12106	12441	16×24	115	37.6	7833	11750	12001
	80	¾ "	17×42	58	39.4	8112	12168	12533	17×30	80	38.6	8042	12063	12329
	80	¾ "	19×48	40	40.3	8201	12301	12715	19×30	65	39.0	8030	12045	12355
	60	¾ "	17×42	78	41.8	8606	12909	13274	17×30	107	40.6	8460	12690	12956
	60	¾ "	19×48	54	43.0	8750	13125	13539	19×30	87	41.2	8483	12724	13034
	60	¾ "	21×48	47	43.1	8770	13156	13631	21×30	71	41.9	8627	12940	13296
200 H. P.	100	¼ stroke	19×48	61	26.2	6070	$9104	$9530	19×30	100	25.2	5930	$8895	$9215
	100	¼ "	21×48	53	26.3	6116	9174	9662	21×30	81	25.6	6024	9036	9402
	100	¼ "	23×54	37	27.0	6207	9310	9860	23×36	56	26.2	6093	9139	9551
	80	¼ "	21×48	69	28.0	6512	9767	10255	21×30	105	27.0	6353	9529	9895
	80	¼ "	23×54	48	28.8	6621	9931	10481	23×36	72	27.8	6465	9697	10109
	80	¼ "	24×54	44	29.0	6667	10000	10615	24×36	66	28.0	6512	9768	10229
	80	¼ "	26×54	37	29.0	6667	10000	10655	26×42	48	28.4	6605	9907	10398
	80	¼ "	27×60	31	29.3	6667	10000	10715	27×42	45	28.7	6598	9897	10433
	60	¼ "	26×54	53	31.7	7287	10931	11586	26×42	69	30.9	7186	10779	11270
	60	¼ "	27×60	43	32.3	7341	11011	11726	27×42	63	31.3	7195	10793	11329
	60	¼ "	28×60	40	32.4	7364	11045	11821	28×48	51	31.3	7195	10793	11375
	60	¼ "	30×60	35	32.6	7409	11114	11954	30×48	45	32.0	7356	11034	11664
	100	½ stroke	15×36	90	29.9	7119	$10678	$10994	15×24	138	28.6	6892	$10338	$10582
	100	½ "	16×42	68	30.5	7176	10765	11110	16×24	123	28.8	6857	10285	10545
	100	½ "	17×42	60	30.9	7271	10906	11281	17×30	91	29.7	7072	10608	10884
	100	½ "	19×48	41	31.6	7349	11023	11449	19×30	67	30.4	7153	10729	11049
	80	½ "	17×42	76	32.7	7694	11541	11916	17×30	105	31.7	7547	11320	11596
	80	½ "	19×48	52	33.7	7837	11756	12182	19×30	85	32.3	7600	11400	11720
	80	½ "	21×48	46	33.7	7837	11756	12244	21×30	69	32.8	7718	11677	12043
	60	½ "	19×48	71	36.2	8419	12629	13043	19×30	115	34.4	8094	12141	12461
	60	½ "	21×48	62	36.3	8442	12663	13151	21×30	94	35.0	8235	12352	12718
	60	½ "	23×54	43	37.5	8621	12931	13481	23×36	65	36.1	8395	12592	13004
	60	½ "	24×54	39	37.7	8667	13000	13615	24×36	59	36.3	8442	12663	13124
	60	½ "	26×54	34	37.7	8667	13000	13655	26×42	45	36.9	8581	12872	13363

Continued on next page.

	STEAM		LONG STROKE ENGINES						SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED		ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
A	B	C	D	E	F	G	H	I	D	E	F	G	H	I
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation (Diam. × Stroke) In. In.	Revolutions per Minute	Per I. H. P. per Hour Lbs	Total Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)	Size and Designation (Diam. × Stroke) In. In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	Total Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)
200 H. P. Concluded.	100	¾ stroke	15 × 36	80	35.9	8548	$12821	$13137	15 × 24	121	34.9	8410	$12615	$12852
	100	¾ "	16 × 42	59	36.8	8659	12988	13323	16 × 24	105	35.2	8381	12572	12823
	100	¾ "	17 × 42	52	37.0	8706	13059	13424	17 × 30	73	36.1	8595	12892	13158
	80	¾ "	16 × 42	74	38.8	9129	13694	14029	16 × 24	131	37.2	8857	13285	13536
	80	¾ "	17 × 42	66	39.0	9176	13765	14130	17 × 30	91	38.2	9095	13642	13908
	80	¾ "	19 × 48	46	39.8	9256	13884	14298	19 × 30	74	38.6	9083	13624	13934
	60	¾ "	19 × 48	61	42.5	9884	14826	15240	19 × 30	99	40.6	9553	14329	14639
	60	¾ "	21 × 48	53	42.7	9930	14895	15370	21 × 30	81	41.3	9718	14577	14933
	60	¾ "	23 × 54	37	43.7	10046	15069	15604	23 × 36	56	42.4	9861	14791	15192
225 H. P.	100	¼ stroke	19 × 48	69	25.8	6750	$10125	$10551	19 × 30	112	24.9	6588	$9882	$10202
	100	¼ "	21 × 48	53	26.3	6881	10321	10809	21 × 30	92	25.3	6706	10059	10425
	100	¼ "	23 × 54	41	26.7	6905	10358	10908	23 × 36	63	25.9	6779	10168	10580
	100	¼ "	24 × 54	38	26.7	6905	10358	10973	24 × 36	58	26.0	6803	10204	10665
	80	¼ "	23 × 54	54	28.5	7371	11057	11607	23 × 36	81	27.5	7198	10797	11209
	80	¼ "	24 × 54	49	28.6	7397	11095	11720	24 × 36	75	27.6	7221	10831	11292
	80	¼ "	26 × 54	42	28.7	7422	11134	11789	26 × 42	55	28.0	7326	10988	11479
	80	¼ "	27 × 60	35	29.0	7415	11122	11837	27 × 42	50	28.3	7318	10978	11514
	80	¼ "	28 × 60	32	29.0	7415	11122	11898	28 × 48	41	28.6	7386	11078	11660
	60	¼ "	27 × 60	48	31.9	8156	12234	12949	27 × 42	70	30.8	7966	11948	12484
	60	¼ "	28 × 60	45	32.0	8181	12273	13049	28 × 48	57	31.3	8095	12142	12724
	60	¼ "	30 × 60	40	32.2	8233	12349	13189	30 × 48	50	31.6	8172	12259	12889
	100	½ stroke	16 × 42	76	30.3	8021	$12031	$12376	16 × 24	138	28.5	7631	$11446	$11706
	100	½ "	17 × 42	67	30.4	8047	12071	12446	17 × 30	103	28.9	7738	11607	11883
	100	½ "	19 × 48	47	31.3	8189	12283	12709	19 × 30	75	29.9	7917	11875	12195
	80	½ "	19 × 48	59	33.2	8688	13029	13455	19 × 30	95	32.1	8494	12741	13061
	80	½ "	21 × 48	51	33.3	8724	13086	13574	21 × 30	78	32.5	8600	12900	13266
	80	½ "	23 × 54	35	34.2	8845	13267	13817	23 × 36	54	33.1	8663	12994	13406
	60	½ "	21 × 48	70	35.7	9340	14010	14498	21 × 30	106	34.5	9129	13693	14059
	60	½ "	23 × 54	48	37.1	9595	14392	14942	23 × 36	73	35.6	9314	13971	14383
	60	½ "	24 × 54	44	37.3	9658	14487	15102	24 × 36	67	35.8	9360	14040	14501
	60	½ "	26 × 54	38	37.3	9658	14487	15142	26 × 42	50	36.2	9471	14196	14687
	60	½ "	27 × 60	31	37.8	9665	14497	15212	27 × 42	41	37.2	9621	14431	14967
	100	¾ stroke	15 × 36	90	35.6	9536	$14304	$14620	15 × 24	136	34.5	9349	$14023	$14260
	100	¾ "	16 × 42	67	36.3	9609	14413	14748	16 × 24	118	34.6	9262	13893	14144
	100	¾ "	17 × 42	59	36.5	9662	14493	14858	17 × 30	81	35.7	9559	14338	14604
	100	¾ "	19 × 48	41	37.2	9733	14699	15113	19 × 30	66	36.1	9553	14329	14639
	80	¾ "	17 × 42	74	38.6	10218	15326	15691	17 × 30	103	37.7	10095	15142	15408
	80	¾ "	19 × 48	51	39.5	10334	15501	15915	19 × 30	83	38.3	10141	15212	15522

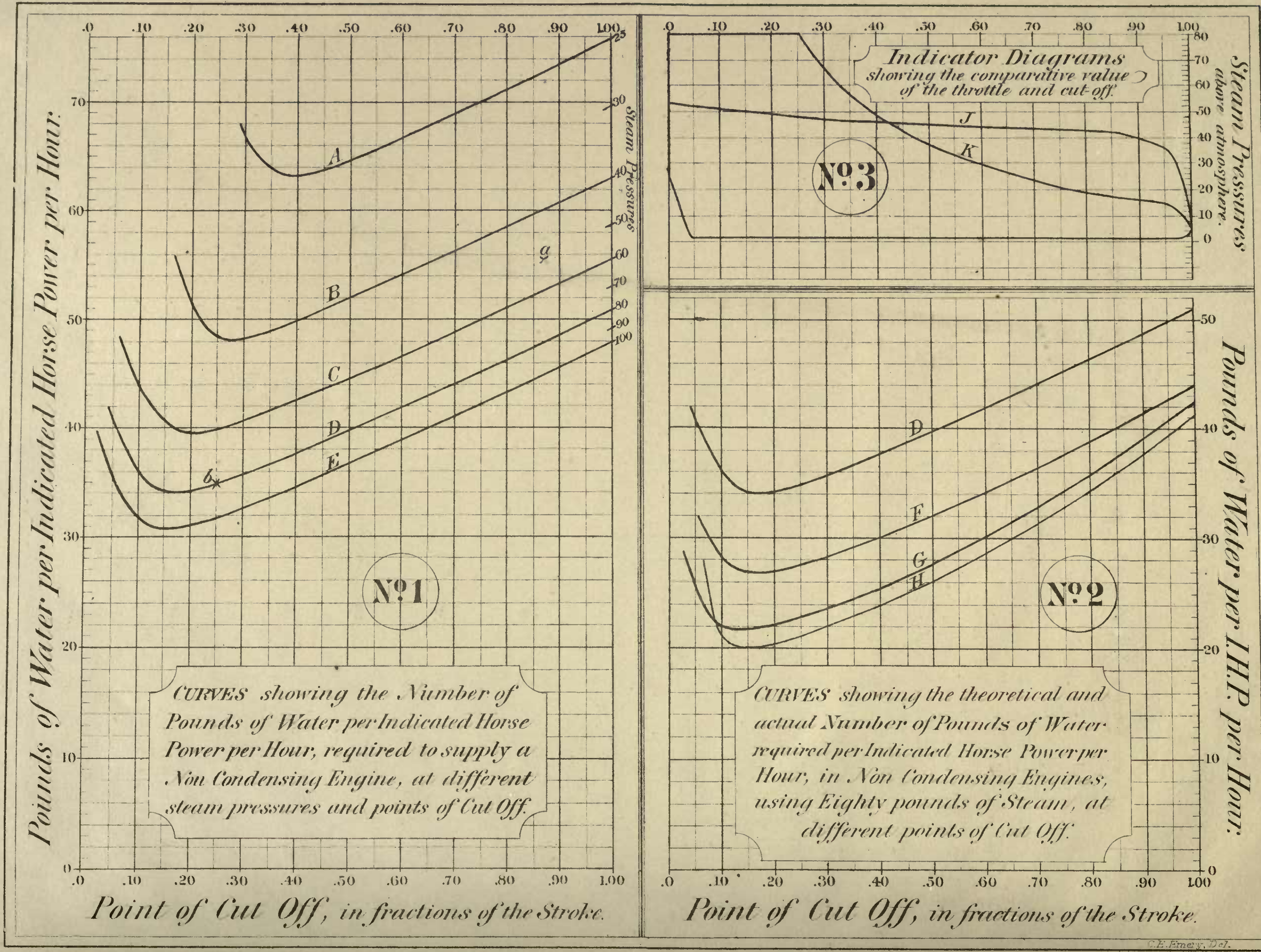
Continued on next page.

	STEAM		LONG STROKE ENGINES							SHORT STROKE ENGINES					
			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED			ENGINE		WATER		COST PER YEAR OF THE POWER NAMED	
A	B	C	D	E	F	G	H	I		D	E	F	G	H	I
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut off	Size and Designation (Diam. × Stroke) In. × In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)		Size and Designation (Diam. × Stroke) In. × In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	TOTAL Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	TOTAL, (Interest on cost of Engine included)
225 H. P. Concluded.	80	¾ stroke	21 × 48	45	39.5	10334	$15501	$15976		21 × 30	68	38.6	10212	$15318	$15674
	60	¾ "	19 × 48	69	41.9	10962	16443	16857		19 × 30	112	40.1	10612	15918	16228
	60	¾ "	21 × 48	60	42.0	10988	16483	16958		21 × 30	91	40.7	10776	16164	16520
	60	¾ "	23 × 54	41	43.3	11198	16797	17332		23 × 36	63	41.8	10930	16396	16797
	60	¾ "	24 × 54	38	43.4	11224	16836	17436		24 × 36	58	42.0	10988	16482	16932
250 H. P.	100	¼ stroke	21 × 48	67	25.7	7465	$11198	$11686		21 × 30	102	25.0	7353	$11029	$11395
	100	¼ "	23 × 54	46	26.5	7615	11422	11972		23 × 36	70	25.6	7442	11163	11575
	100	¼ "	24 × 54	42	26.5	7615	11422	12037		24 × 36	64	25.7	7465	11198	11659
	100	¼ "	26 × 54	36	26.4	7586	11379	12034		26 × 42	47	25.9	7529	11294	11785
	100	¼ "	27 × 60	30	26.7	7586	11379	12094		27 × 42	43	26.2	7529	11294	11830
	80	¼ "	23 × 54	60	28.2	8102	12153	12703		23 × 36	90	27.2	7907	11860	12272
	80	¼ "	24 × 54	55	28.3	8131	12197	12812		24 × 36	83	27.4	7965	11947	12408
	80	¼ "	26 × 54	46	28.4	8161	12241	12896		26 × 42	61	27.8	8081	12122	12613
	80	¼ "	27 × 60	38	28.8	8182	12273	12988		27 × 42	56	28.0	8023	12034	12570
	80	¼ "	28 × 60	36	28.8	8182	12273	13049		28 × 48	45	28.4	8148	12222	12804
	80	¼ "	30 × 60	31	29.0	8239	12358	13198		30 × 48	39	28.6	8218	12327	12957
	60	¼ "	28 × 60	50	31.6	8979	13469	14245		28 × 48	63	31.0	8908	13362	13944
	60	¼ "	30 × 60	44	31.9	9063	13594	14434		30 × 48	56	31.2	8966	13448	14078
	100	½ stroke	17 × 42	75	30.0	8824	$13235	$13610		17 × 30	114	28.8	8571	$12857	$13133
	100	½ "	19 × 48	52	30.9	8983	13474	13910		19 × 30	84	28.8	8471	12706	13026
	100	½ "	21 × 48	43	31.3	9099	13648	14136		21 × 30	73	29.9	8788	13182	13548
	80	½ "	19 × 48	66	32.9	9564	14346	14772		19 × 30	106	31.4	9235	13852	14172
	80	½ "	21 × 48	57	33.0	9593	14390	14878		21 × 30	87	32.1	9435	14125	14491
	80	½ "	23 × 54	39	33.0	9483	14224	14774		23 × 36	60	32.9	9560	14340	14752
	80	½ "	24 × 54	36	33.0	9483	14224	14839		24 × 36	55	32.9	9560	14340	14801
	60	½ "	23 × 54	53	36.6	10515	15773	16323		23 × 36	81	35.1	10197	15295	15707
	60	½ "	24 × 54	49	36.9	10613	15920	16535		24 × 36	74	35.4	10291	15436	15897
	60	½ "	26 × 54	42	36.9	10613	15920	16575		26 × 42	56	36.0	10465	15698	16189
	60	½ "	27 × 60	34	37.4	10625	15938	16653		27 × 42	50	36.4	10460	15690	16226
	60	½ "	28 × 60	32	37.4	10625	15938	16714		28 × 48	41	36.8	10563	15845	16427
	100	¾ stroke	16 × 42	74	35.9	10559	$15838	$16173		16 × 24	131	34.4	10238	$15357	$15608
	100	¾ "	17 × 42	66	36.2	10647	15971	16336		17 × 30	91	35.4	10536	15804	16070
	100	¾ "	19 × 48	45	37.0	10756	16134	16548		19 × 30	74	35.7	10494	15741	16051
	80	¾ "	19 × 48	57	39.1	11366	17049	17463		19 × 30	93	37.8	11113	16669	16979
	80	¾ "	21 × 48	50	39.2	11395	17093	17568		21 × 30	75	38.3	11259	16888	17244
	80	¾ "	23 × 54	35	39.9	11463	17195	17730		23 × 36	52	39.0	11337	17005	17406
	60	¾ "	21 × 48	67	41.6	12093	18140	18615		21 × 30	102	39.1	11360	17040	17396
	60	¾ "	23 × 54	46	42.9	12328	18491	19026		23 × 36	70	41.3	12000	18000	18401
	60	¾ "	24 × 54	42	43.1	12385	18578	19178		24 × 36	64	41.6	12093	18139	18589
	60	¾ "	26 × 54	36	43.0	12356	18534	19172		26 × 42	47	42.1	12238	18357	18835
	60	¾ "	27 × 60	30	43.4	12330	18494	19191		27 × 42	43	42.6	12241	18362	18885

A	B	C	LONG STROKE ENGINES — ENGINE D	E	WATER F	G	COST PER YEAR OF THE POWER NAMED H	I	SHORT STROKE ENGINES — ENGINE D	E	WATER F	G	COST PER YEAR OF THE POWER NAMED H	I
NET HORSE POWER	STEAM: Pressure above Atmosphere in pounds per square inch	STEAM: Point of Cut-off	Size and Designation (Diam. × Stroke) In. In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	Total Per Hour for Net Horse Power named Lbs.	For Coal at $8 00 per Ton	Total, (Interest on cost of Engine included)	Size and Designation (Diam. × Stroke) In. In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	Total Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)
275 H. P.	100	¼ stroke	21 × 48	74	25.5	8154	$12231	$12719	21 × 30	112	24.8	8023	$12034	$12400
	100	¼ “	23 × 54	51	26.2	8295	12443	12993	23 × 36	77	25.4	8116	12174	12586
	100	¼ “	24 × 54	46	26.2	8282	12422	13037	24 × 36	71	25.5	8163	12244	12705
	100	¼ “	26 × 54	40	26.2	8282	12422	13077	26 × 42	52	25.7	8218	12327	12818
	100	¼ “	27 × 60	33	26.4	8250	12375	13090	27 × 42	47	25.9	8187	12280	12816
	100	¼ “	28 × 60	30	26.5	8281	12422	13198	28 × 48	39	26.1	8250	12375	12957
	80	¼ “	24 × 54	61	28.0	8851	13277	13892	24 × 36	88	27.2	8651	12977	13438
	80	¼ “	26 × 54	51	28.2	8914	13371	14026	26 × 42	67	27.5	8794	13190	13681
	80	¼ “	27 × 60	42	28.5	8906	13359	14074	27 × 42	61	27.8	8787	13181	13717
	80	¼ “	28 × 60	39	28.6	8937	13406	14182	28 × 48	50	28.1	8882	13323	13905
	80	¼ “	30 × 60	35	28.7	9084	13625	14465	30 × 48	43	28.4	8988	13483	14113
	60	¼ “	30 × 60	48	31.6	9875	14813	15653	30 × 48	62	30.9	9767	14651	15281
	100	½ stroke	19 × 48	57	30.4	9721	$14581	$15007	19 × 30	92	29.4	9472	$14208	$14528
	100	½ “	21 × 48	47	30.9	9881	14821	15309	21 × 30	80	29.5	9553	14329	14695
	100	½ “	23 × 54	34	31.6	9989	14984	15534	23 × 36	52	30.5	9744	14616	15028
	80	½ “	19 × 48	73	32.6	10424	15636	16062	19 × 30	117	31.2	10094	15141	15461
	80	½ “	21 × 48	63	32.7	10456	15685	16173	21 × 30	96	31.7	10240	15360	15726
	80	½ “	23 × 54	43	33.7	10652	15978	16528	23 × 36	66	32.5	10384	15576	15988
	80	½ “	24 × 54	40	33.8	10684	16026	16641	24 × 36	60	32.7	10465	15697	16158
	60	½ “	23 × 54	58	36.3	11474	17211	17761	23 × 36	89	34.8	11130	16695	17107
	60	½ “	24 × 54	54	36.4	11502	17253	17868	24 × 36	82	35.0	11151	16726	17187
	60	½ “	26 × 54	46	36.5	11537	17306	17961	26 × 42	61	35.6	11384	17076	17567
	60	½ “	27 × 60	38	37.1	11594	17391	18106	27 × 42	55	36.0	11379	17069	17605
	60	½ “	28 × 60	35	37.2	11625	17438	18214	28 × 48	45	36.4	11506	17259	17841
	60	½ “	30 × 60	31	37.4	11687	17531	18371	30 × 48	39	36.9	11664	17496	18126
300 H. P.	100	¼ stroke	23 × 54	55	26.0	8965	$13448	$13998	23 × 36	84	25.2	8791	$13186	$13598
	100	¼ “	24 × 54	50	26.0	8965	13448	14063	24 × 36	77	25.3	8825	13238	13699
	100	¼ “	26 × 54	43	26.1	9000	13500	14155	26 × 42	56	25.5	8895	13343	13834
	100	¼ “	27 × 60	36	26.3	8966	13449	14164	27 × 42	52	25.7	8839	13259	13795
	100	¼ “	28 × 60	33	26.3	8966	13449	14225	28 × 48	42	25.9	8931	13397	13979
	80	¼ “	27 × 60	46	28.3	9648	14472	15187	27 × 42	67	27.5	9483	14224	14760
	80	¼ “	28 × 60	43	28.4	9625	14438	15214	28 × 48	54	27.9	9621	14431	15013
	80	¼ “	30 × 60	38	28.5	9716	14574	15414	30 × 48	47	28.2	9724	14586	15216
	100	½ stroke	19 × 48	62	30.2	10535	$15802	$16228	19 × 30	101	28.9	10200	$15300	$15620
	100	½ “	21 × 48	51	30.5	10640	15959	16447	21 × 30	86	29.4	10377	15565	15931
	100	½ “	23 × 54	37	31.3	10793	16190	16740	23 × 36	56	30.3	10570	15855	16267
	100	½ “	24 × 54	34	31.3	10793	16190	16805	24 × 36	52	30.4	10605	15907	16368

Continued on next page.

A	B	C	D		E	F	G	H	I	D		E	F	G	H	I
	STEAM		LONG STROKE ENGINES							SHORT STROKE ENGINES						
			ENGINE			WATER		COST PER YEAR OF THE POWER NAMED		ENGINE			WATER		COST PER YEAR OF THE POWER NAMED	
NET HORSE POWER	Pressure above Atmosphere in pounds per square inch	Point of Cut-off	Size and Designation: Diam. In.	Size and Designation: Stroke In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	Total Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)	Size and Designation: Diam. In.	Size and Designation: Stroke In.	Revolutions per Minute	Per I. H. P. per Hour Lbs.	Total Per Hour for Net Horse Power named Lbs.	For Coal at $8.00 per Ton	Total, (Interest on cost of Engine included)
300 H. P. Concluded.	80	½ stroke	21 × 48		68	32.4	11302	$16953	$17441	21 × 30		104	31.3	11047	$16570	$16936
	80	½ "	23 × 54		47	33.3	11483	17224	17774	23 × 36		72	32.2	11163	16744	17156
	80	½ "	24 × 54		43	33.4	11517	17276	17891	24 × 36		66	32.4	11303	16954	17415
	80	½ "	26 × 54		37	33.4	11517	17276	17931	26 × 42		48	32.8	11442	17163	17654
	80	½ "	27 × 60		30	33.9	11557	17335	18050	27 × 42		44	33.1	11414	17121	17657
	60	½ "	26 × 54		50	36.2	12437	18655	19310	26 × 42		67	35.1	12244	18366	18857
	60	½ "	27 × 60		41	36.8	12545	18818	19533	27 × 42		60	35.6	12278	18417	18953
	60	½ "	28 × 60		38	36.9	12580	18869	19645	28 × 48		49	36.1	12448	18672	19254
	60	½ "	30 × 60		34	37.1	12648	18972	19812	30 × 48		42	36.5	12586	18879	19509
350 H. P.	100	¼ stroke	24 × 54		58	25.7	10340	$15510	$16125	24 × 36		90	25.0	10174	$15261	$15722
	100	¼ "	26 × 54		50	25.7	10339	15509	16164	26 × 42		66	25.2	10256	15384	15875
	100	¼ "	27 × 60		42	25.9	10301	15452	16167	27 × 42		60	25.4	10218	15328	15864
	100	¼ "	28 × 60		39	25.9	10301	15452	16228	28 × 48		49	25.6	10298	15447	16029
	100	¼ "	30 × 60		34	26.1	10381	15571	16411	30 × 48		43	25.8	10494	15740	16370
	80	¼ "	30 × 60		44	28.2	11216	16824	17664	30 × 48		55	27.7	11144	16716	17346
	100	½ stroke	19 × 48		72	29.7	12087	$18131	$18557	19 × 30		117	28.5	11730	$17595	$17915
	100	½ "	21 × 48		60	30.0	12209	18314	18802	21 × 30		100	28.7	11812	17718	18084
	100	½ "	23 × 54		44	30.9	12431	18647	19197	23 × 36		66	29.8	12130	18195	18607
	100	½ "	24 × 54		40	30.9	12431	18647	19262	24 × 36		61	29.9	12163	18244	18705
	80	½ "	23 × 54		55	32.8	13195	19793	20343	23 × 36		83	31.8	12942	19413	19825
	80	½ "	24 × 54		50	33.0	13276	19914	20529	24 × 36		76	32.0	13023	19534	19995
	80	½ "	26 × 54		43	33.0	13276	19914	20569	26 × 42		56	32.4	13186	19779	20270
	80	½ "	27 × 60		36	33.3	13245	19867	20582	27 × 42		51	32.7	13155	19733	20269
	80	½ "	28 × 60		33	33.3	13245	19867	20643	28 × 48		42	32.9	13236	19853	20435
	60	½ "	27 × 60		48	36.2	14398	21597	22312	27 × 42		70	34.9	14040	21060	21596
	60	½ "	28 × 60		45	36.3	14438	21656	22432	28 × 48		57	35.5	14201	21302	21884
	60	½ "	30 × 60		39	36.6	14670	22006	22846	30 × 48		49	36.0	14483	21725	22355



Pounds of Water per Indicated Horse Power per Hour:
Steam Pressures
25
30
40
50
60
70
80
90
100
A
B
C
D
E
b
g
Nº1
CURVES showing the Number of Pounds of Water per Indicated Horse Power per Hour, required to supply a Non Condensing Engine, at different steam pressures and points of Cut Off.
Point of Cut Off, in fractions of the Stroke.
Indicator Diagrams showing the comparative value of the throttle and cut-off.
Steam Pressures above atmosphere.
J
K
Nº3
Pounds of Water per I.H.P. per Hour:
D
F
G
H
Nº2
CURVES showing the theoretical and actual Number of Pounds of Water required per Indicated Horse Power per Hour, in Non Condensing Engines, using Eighty pounds of Steam, at different points of Cut Off.
Point of Cut Off, in fractions of the Stroke.
C.E. Emery, Del.

Explanation of Diagrams.

DIAGRAM No. 1 is intended to show, by inspection, the number of pounds of water required per hour for one Indicated Horse Power, at different steam pressures and points of cut-off.

In this Diagram the vertical lines drawn through .0, .20, .30, etc., show the proportion of stroke at which it is assumed that the steam is cut-off, in various cases—the figures expressing decimally that proportion.

The horizontal lines drawn through 70, 60, 50, etc., show the number of pounds of water required per hour for one Indicated Horse Power.

The curved lines A, B, C, D and E refer respectively to the steam pressures named:

The curve	A	being the line	for	pressure of	25	lbs.
"	B	"	"	"	40	"
"	C	"	"	"	60	"
"	D	"	"	"	80	"
"	E	"	"	"	100	"

To find from Diagram No. 1 the number of pounds of water per Indicated Horse Power per hour at a pressure of steam and proportion of cut-off named, suppose the pressure to be 60 lbs. and proportion of cut-off .30:

Find the intersection of the vertical line passing through .30 with the curved line C representing 60 lbs. steam pressure. It will be seen that a horizontal line drawn through this intersecting point will pass through 41, in the vertical line showing pounds of water, showing that, for a steam pressure of 60 lbs., with proportion of cut-off .30, the pounds of water per Indicated Horse Power per hour is 41.

It will be seen, on examination, that the point of cut-off, most economical in water, varies with the pressure of steam.

When the cylinder exceeds one cubic foot capacity, the pounds of water will be somewhat less than is shown by the Diagram.

The lowest point of each curve shows the least number of pounds of water and the most economical point of cut-off for each steam pressure.

The curves A, B, C, D and E have been obtained from a large number of experiments made with a small engine, the experiments with each pressure furnishing a series of points through which a curve was drawn.

In Diagram No. 2 the curves D and F are presented to show the difference in pounds of water when the cylinder is less than one cubic foot capacity, and when the cylinder is greater than ten cubic feet capacity; a steam pressure of 80 lbs. being used in both cases. The curves H and G are presented to show the number of pounds of water which would be required by calculation according to Mariotte's law and the well-known tables of specific volumes. Curve H being the theoretical curve where there are no clearances and the curve G the corresponding curve when the capacity of clearances and ports equals one-twentieth of the piston development.

There are four conditions which influence the economy of a non-condensing steam engine, viz: 1st—*The steam pressure;* 2d—*The amount of expansion;* 3d—*The speed of revolution*, and 4th—*The size of the cylinder.* The relative and actual value of each of these has been determined by careful experiment. By combining together the facts thus obtained, the cost of the Indicated Horse Power has been ascertained in pounds of water per hour for any desired steam pressure, point of cut-off, speed of revolution or size of engine. Such results, for the regular sizes of the engines manufactured at The Novelty Iron Works, are presented in the tables on page 7 *et seq.*, in columns F and F, headed "Water per Indicated Horse Power per hour." The tables are particularly useful in showing the exact value of several of the methods of producing economy of steam.

The economy, due to an increase in the size of the engine, is shown in the tables by comparing different horse powers, produced under like conditions, and necessarily, therefore, in different sized engines. It will be found, however, by selecting any *particular* horse power, that the *highest steam pressures* and *revolutions* and *shortest points of cut-off* mentioned are those which show the *greatest economy* of steam. When these three conditions are all favorable, at the same time, the maximum economy is obtained, but when one or more only is favorable, the results are so modified as often to appear contradictory. For instance, the short stroke engines are, in all cases, a little more economical than the corresponding long strokes, and the small engines of each class are more economical than the large ones, in all cases where the steam pressures, points of cut-off and power developed are the same; for, although the smaller engine, at the same speed, would be less economical, at the higher speeds, necessary to produce the same power, the gain, due to the high speed, overbalances the loss due to the smaller size of cylinder, as is shown all through the tables.

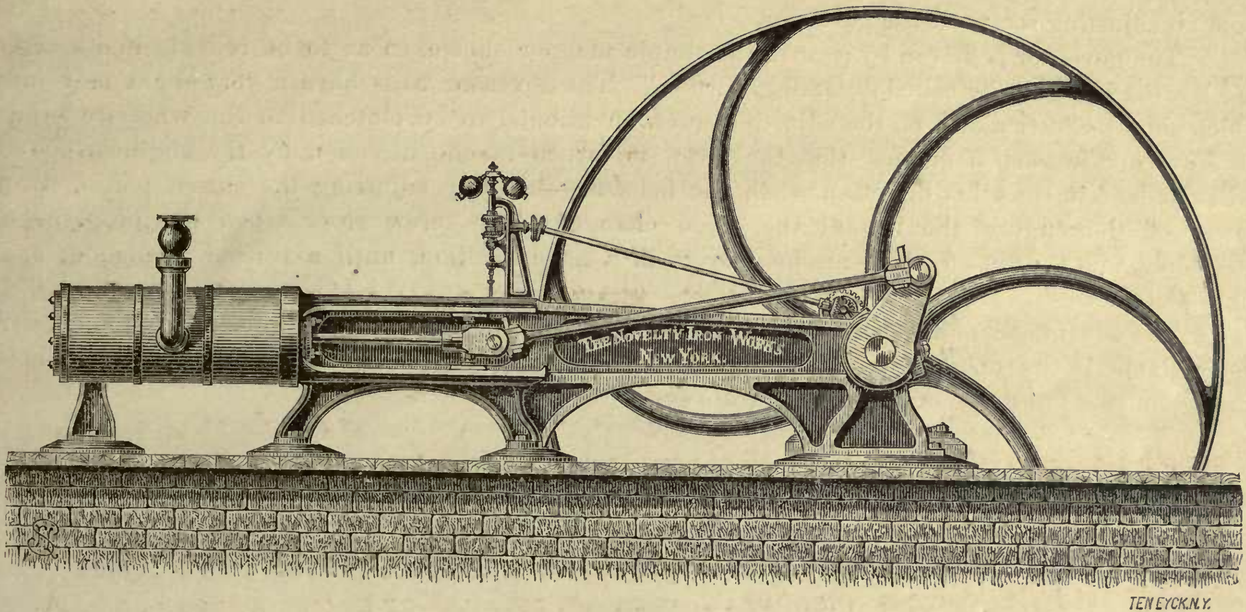
Selecting for more particular comparison, 60 Horse Power, on page 12, we find that using a steam pressure of 60 lbs. cut-off at *one-quarter* of the stroke, in a 17×42 engine, running 49 revolutions, the cost of the Indicated Horse Power is 33.9 lbs. of water per hour; while, by using 100 lbs. steam pressure, cut off at *one-half* of the stroke, in a 10×24 engine, running 94 revolutions, the cost is only 31.6 lbs. of water per hour. So likewise, the same power can be obtained in a 9×24 engine, at 102 revolutions, using 100 lbs. steam pressure, cut off at *three-quarters* of the stroke, more economically than it can in a 14×36 engine at 55 revolutions, using 60 lbs. steam pressure, cut off at *one-half* of the stroke. In these cases, the higher steam pressure and revolutions overbalance greatly the losses due to the less expansion and smaller engine.

J and K (No. 3) are Indicator Diagrams, which are intended to show the comparative value of regulating speed by the throttle or by the cut-off. The diagrams are of the same area and were taken from the same engine. The pressure in the steam pipe was 80 lbs. above the atmosphere, in both cases.

Diagram J was taken with the throttle partially closed and the steam cut off in the cylinder by the lap of the main valve, at seven-eighths of the stroke.

Diagram K was taken with the steam cut off at one-fourth of the stroke, by an independent valve. It has been usual to compare such diagrams by assuming that there is used, in each case, only a cylinder full of steam of the terminal pressure. This assumption has been found to be incorrect in practice. We may, however, compare the two systems of working by referring to the curves on Diagram No. 1. The initial pressure of Indicator Diagram J is 53 lbs., and as the point of cut-off is seven-eighths of the stroke, by referring to No. 1 we find, at the point *a*, that an engine, working under these conditions, requires 56 lbs. of water per indicated horse power per hour. The initial pressure of diagram K is 80 lbs., and the point of cut-off being one-fourth of the stroke, we find at *b*, in like manner as before, that the water required is only 35 lbs. per hour.

Non-Condensing Stationary Steam Engine.



THE engraving represents one of the Non-Condensing Stationary Steam Engines built at The Novelty Iron Works, New York.

The bed-plate of the engine is of the style introduced many years ago by The Novelty Iron Works, and has since been extensively copied by other manufacturers. It may be described as a strong cast-iron box, one end of which is so constructed as to form a cylinder head and the other a pillow block for the main shaft. The main slides also form part of the same casting as do also the strong legs and broad feet upon which the frame is supported. This bed-plate has the advantages that the metal is disposed directly in the line of the strains, and neither the cylinder, main slides or pillow block can work loose or get out of proper adjustment. The legs upon which the frame rests are put under the slides and under the shaft, which is an additional security against any springing of the frame from the oblique strains brought to bear at these points by the connecting rod and crank. The cylinder being attached at only one end to the bed-plate is free to expand when heated without any alteration of shape—the outer end simply sliding over a small stationary standard which carries part of the weight.

The steam is admitted to and from the cylinder by a plain slide valve, so arranged that the cylinder ports are very short and direct, and the amount of steam required to fill the clearance and port is much less than in any other arrangement in use.

The cut-off consists of two plates sliding on the back of the main valve and operated by a separate eccentric. This cut-off is either set at a fixed point, in the usual way, or made so that it can be adjusted by hand, from zero to seven-eighths stroke, by simply turning the cut-off valve stem: Preferably, however, the adjustment is made by the governor through a simple arrangement which we will try and make understood without illustrations. The cut-off is varied by drawing together or spreading apart the cut-off plates. To accomplish this by the governor, the plates are operated by separate rods which pass outside the chest and connect to the ends of a small double-ended vertical lever, the center of which receives motion from the cut-off eccentric. The double-ended lever has attached to it a horizontal arm, which is operated to adjust the plates by a vertical movement derived from an adjusting screw on the governor.

The governor is driven by gear in the simple manner shown, so as to be reliable in its action, and is what is ordinarily called a "mill governor." The governor balls have a very slight movement, which simply causes a disk on the adjusting screw mentioned to be clutched to the wheels operating the governor in such a manner that the screw is turned in one direction by the engine when the balls rise, and in the other direction when the balls fall—thereby adjusting the cut-off plates, by the power of the engine, the instant the speed changes. The screw stops when the proper speed is restored, and the cut-off plates are held by it, in a fixed position, until a further change of speed takes place.

The advantages of this form of governor cut-off are, that it is simple in construction, positive and reliable in its operation, and, unlike any common governor, gives exactly the same speed throughout the full range of power and steam pressure.

Sizes of Engines Recommended for Given Powers.

THE tables on page 7 *et seq.*, show conclusively that any particular horse power can be obtained in a variety of ways in either of a large number of engines of different sizes. All the cases are entirely practical if the engines are especially designed to operate under the conditions stated, but there are few instances in which it would be desirable to use the extremes mentioned. The proper size of an engine, and the conditions under which it is to be run, must be determined by the requirements of each particular case.

One great difficulty in fixing the proper size of an engine is to know what power is actually required by the purchaser. Too often this is underrated, whence for safety manufacturers have been in the habit of furnishing an engine large enough for all contingencies, and therefore, in many cases, too large to do the work economically. We believe that, with the complete guide as to power furnished by our tables, it is safe to select engines properly proportioned for the work they are expected to perform. For ordinary practice we recommend that the selection be made by the following table:

TABLE

SHOWING

Recommended Sizes of Engines for given Horse Powers.

Sizes of Long Stroke Engines (Diameter × Stroke, Inches)	Net Horse Power	Sizes of Short Stroke Engines (Diameter × Stroke, Inches)	Sizes of Long Stroke Engines (Diameter × Stroke, Inches)	Net Horse Power	Sizes of Short Stroke Engines (Diameter × Stroke, Inches)
5 × 12	**5**	5 × 9	16 × 42	**90**	16 × 24
6 × 16	**10**	6 × 9	17 × 42	**100**	17 × 30
7 × 20	**15**	7 × 12	19 × 48	**125**	19 × 30
8 × 20	**20**	8 × 12	21 × 48	**150**	21 × 30
9 × 24	**25**	9 × 15	23 × 54	**175**	23 × 36
10 × 24	**30**	10 × 15	24 × 54	**200**	24 × 36
11 × 30	**40**	11 × 18	26 × 54	**225**	26 × 42
12 × 30	**50**	12 × 18	27 × 60	**250**	27 × 42
13 × 36	**60**	13 × 21	28 × 60	**275**	28 × 48
14 × 36	**70**	14 × 21	30 × 60	**300**	30 × 48
15 × 36	**80**	15 × 24			

The engines in the foregoing table are of sufficient size to furnish the net horse powers named when using 80 lbs. of steam, cut off at one-fourth of the stroke; and the same power may be obtained in the same engine, with greater economy, by increasing the steam pressure and shortening the point of cut-off, and with less economy by reducing the steam pressure and following farther in the stroke. In cases when there is any uncertainty as to the amount of power that will be required, or when it is desired to have an engine that will do its work with very little attention, it is best to select for the given power an engine one size larger than is set opposite that power in the above table.

Boilers.

THE tables on page 7, *et seq.*, giving dimensions, &c., of the engines which will furnish a desired horse power, state in columns G and G the number of pounds of water required to be evaporated to produce that horse power. That evaporation can be provided by boilers of various kinds and proportion of parts. Local and other considerations often decide the kind of boiler. In order, therefore, to afford the opportunity of selecting the boiler that shall be of adequate evaporative power, and be of the kind preferred, a table is given at the close of this article, of the four kinds of boilers most generally in use; giving, for various dimensions of each kind, the evaporative capacity of each boiler.

In this table the proportion of parts are those most generally in use, which are not always those that will give the greatest evaporation per pound of coal. Thus a cylinder boiler 18 inches in diameter and 18 feet long will evaporate about 7 lbs. of water per pound of coal, but if made 36 feet long it will evaporate fully 8 lbs. per pound of coal.

The amount of water evaporated per pound of coal under favorable conditions by each of the three kinds of boilers when proportioned as in our table, has been ascertained by careful experiment and is given below:

NAME OF BOILER.	Water evaporated per pound of Coal, at 80 lbs. pressure, from temperature of 160°.	RELATIVE EVAPORATION.
	Lbs.	
Plain Cylinder Boiler,	6.91	1.00
Cylinder Flue "	7.91	1.14
" Tubular "	9.15	1.32

The performance of a locomotive or marine tubular boiler is substantially the same as that of the cylinder tubular, when similarly proportioned.

In preparing the table of evaporative capacities of boilers, an allowance ot over 25 per cent. has been made to provide for differences of management, draft and fuel which may be met with.

The headings of the columns in the table show what are the particulars stated.

It will be seen that columns 10 and 11 show the number of pounds of water evaporated, in one case from 60° temperature, and in the other from 160°.

In cases where a single boiler of dimensions stated will not furnish the evaporation required, modifications in number and length will be necessary to produce the required evaporation.

For example, if a person select for 100 horse power, an engine 17 inches diameter, 42 inches stroke, to run at 57 revolutions per minute, and use 80 pounds of steam cut off at ¼, the total quantity of water required per hour would equal 3,488 lbs. No single boiler in the list will evaporate this quantity, but it may be obtained by using

2	Cylinder	Tubular	Boilers of	55	inches	diameter,	or
3	"	"	"	47	"	"	"
2	"	Flue	"	56	"	"	"
3	"	"	"	44	"	"	"
4	Plain	Cylinder	"	36	"	"	"
5	"	"	"	33	"	"	

As a general rule it is true economy to select a boiler a little larger than is required. The variations from the table in either direction should not amount to more than 10 per cent. The amount of water evaporated by either of the plain cylinder boilers may be varied, within large limits, by altering the length of the boiler. If the grate surface and height of bridge walls be proportionately altered the economy will not be sensibly influenced. The cylinder flue and cylinder tubular boilers may be shortened to reduce the heating surface, and will evaporate a quantity of water fully proportioned to the reduced length, but at a small sacrifice of economy.

TABLES

SHOWING THE PRINCIPAL DIMENSIONS OF THE

High Pressure Steam Boilers

BUILT AT

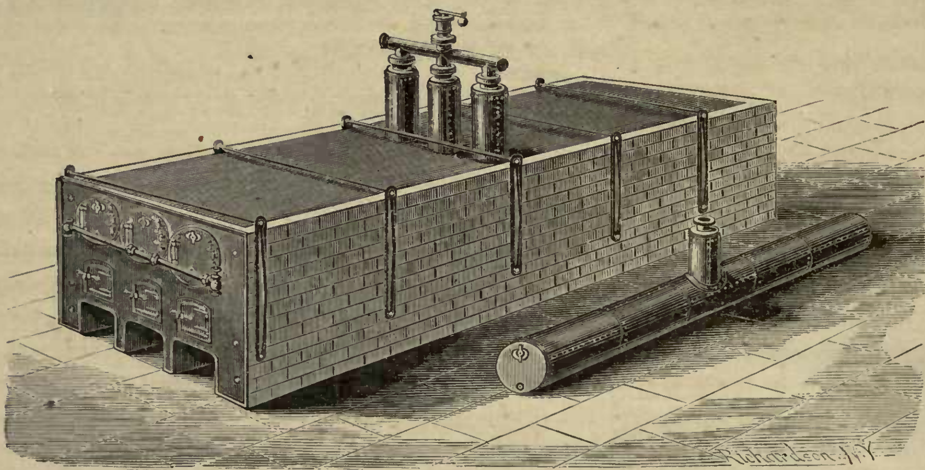
THE NOVELTY IRON WORKS, NEW YORK,

AND THE

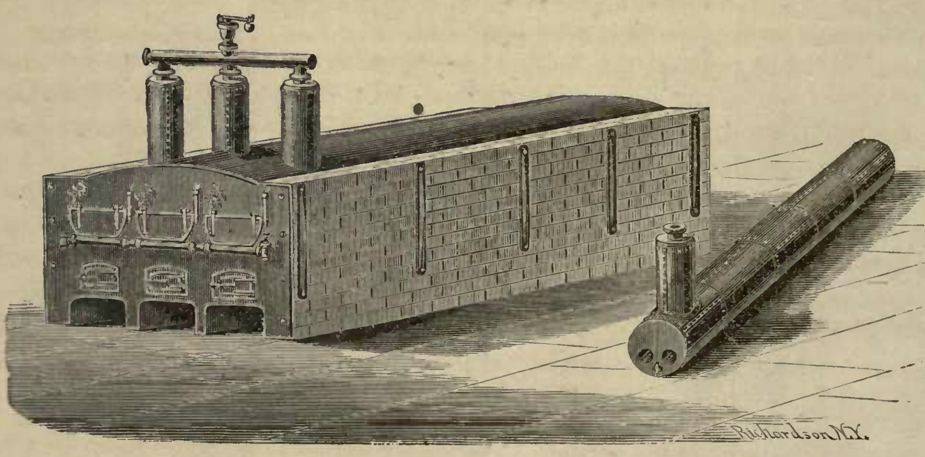
Water Evaporated per Hour by the same from the Temperatures of 60° and 160° Fahrenheit.

KIND OF BOILER	DIMENSIONS								WATER Evaporated per Hour at 80 lbs. Pressure from Temperature of	
	SHELL OF BOILER		FLUES OR TUBES		STEAM DRUM		GRATE SURFACE	HEATING SURFACE	60°	160°
	DIAMETER	LENGTH	NUMBER	DIAMETER	DIAMETER	HEIGHT				
	Inches	Feet		Inches	Inches	Inches	Square Feet	Square Feet	Lbs.	Lbs.
PLAIN CYLINDER BOILERS.	18	18.0			12	24	3.8	42	202	221
	21	21.0			14	28	5.3	58	280	306
	24	24.0			15	30	6.8	75	363	395
	27	27.0			16	32	8.6	95	458	501
	30	30.0			18	36	10.7	118	569	622
	33	33.0			20	36	13.0	143	689	754
	36	36.0			20	40	15.4	170	819	896
CYLINDER FLUE BOILERS.	24	8.5	2	6.5	12	24	3.3	56	200	219
	30	13.0	2	9.0	15	30	6.6	112	400	438
	36	16.0	2	11.0	18	30	9.9	168	600	657
	38	18.0	2	12.5	22	36	12.2	207	739	809
	40	20.5	2	13.5	24	42	14.8	252	900	985
	42	22.0	2	14.5	26	42	16.9	288	1028	1126
	44	23.0	2	15.0	26	42	18.4	313	1117	1224
	48	24.5	2	16.0	27	48	21.1	359	1282	1404
	52	26.5	2	17.5	28	48	24.9	423	1500	1654
	56	29.0	2	19.0	30	54	29.5	501	1789	1959
	60	31.5	2	20.5	32	54	34.5	586	2291	2092
	66	36.0	2	23.0	36	60	43.8	745	2660	2913
CYLINDER TUBULAR BOILERS.	22	6.5	18	2.0	12	24	2.9	80	187	205
	30	7.0	22	2.5	15	30	5.6	157	367	402
	36	8.5	34	2.5	18	30	8.2	229	536	586
	40	9.0	42	2.5	22	36	10.5	294	688	753
	44	11.0	40	3.0	24	42	14.7	409	957	1047
	47	12.5	34	3.5	26	42	16.6	466	1090	1193
	51	14.0	34	4.0	28	48	21.1	592	1385	1516
	55	14.5	42	4.0	30	54	26.5	742	1736	1900
	60	15.0	52	4.0	34	54	33.2	931	2178	2383
	66	15.0	60	4.0	36	60	38.3	1072	2508	2744
LOCOMOTIVE BOILERS.							3.0	85	199	218
							5.9	165	386	422
							8.8	245	573	627
							11.4	320	749	819
							14.3	400	936	1024
							17.1	480	1123	1229
							22.5	630	1474	1613
							27.7	775	1814	1984

Plain Cylinder Boilers.



Cylinder Flue Boilers.



The above boilers are, if desired, furnished complete, with Cast Iron Fronts and Doors, Grate Bars and Bearers, Buckstaves and Bolts, Cast and Wrought Iron Pipe, Safety, Feed and Stop Valves, Guage Cocks, Water Guages and all other fixtures necessary in setting boilers. Complete plans are also furnished of the foundation and brickwork.

For sizes and evaporating power of the above boilers, see previous page.

See also the article headed "Boilers," on page 29.

Horse Power of Boilers.

(The following remarks on Horse Power of Boilers, Boiler Explosions, &c., are from a paper read before the Connecticut Academy of Sciences, by W. P. TROWBRIDGE.)

The term "Horse Power," in its application to boilers, has heretofore been no less indefinite than the same term in its application to the engine. It has been customary to fix upon some unit of heating surface as the unit of the horse power of the boiler. The boiler is supposed to furnish a definite amount of steam at the working pressure employed, this amount depending on the heating surface; and the utilization of all this steam, under the most favorable conditions, would thus furnish, through the medium of an engine, a certain rate of work, or a certain Horse Power. An inspection of the preceding tables of engines is sufficient, however, to show that the same quantity of water evaporated by a boiler will effect different quantities of work in the same engine, or in different engines, under various conditions of working; these conditions being the pressure, the degree of expansion, and the speed of the piston. The rate of work of the boiler thus depends entirely on the engine; and the term "Horse Power," as usually applied, has no very definite signification. The effective power of a given boiler-apparatus, including the chimney, or power for producing the draft, may, perhaps, be estimated by supposing all the steam which such a boiler can produce at a given pressure, to be utilized under the most favorable circumstances conceivable in practice. But it is still apparent that the power of the boiler is dependent upon the most favorable utilization of the steam.

A more definite and positive mode of determining the true theoretical or disposable Horse Power of boilers may be derived from the investigations of Prof. Zeuner, Director of the Mining School at Freiberg, in his work on "The Mechanical Theory of Heat." This new method gives the maximum disposable rate of work, without reference to the engine; and hence, when an engine is using all the steam a boiler can produce, the boiler Horse Power may furnish a standard for the economy of the engine.

The method depends on the following considerations:

If we suppose the whole work of the boiler to be expended in producing a flow of steam through a small orifice, the velocity of the issuing steam is independent of the diameter of the orifice, and dependent only on the pressure; but the quantity of steam which flows through in pounds, will, of course, depend on the diameter of the orifice; and if the size of the orifice be just sufficient to allow all the steam to escape which the boiler can produce, the quantity which flows through in pounds, in each second, will be just equal to the amount which the boiler will produce in a second. The work of the boiler each second will be expended in imparting to this quantity of water, or steam, the velocity with which it issues from the orifice, and will be equal to the LIVING FORCE of the mass in motion with the issuing velocity.

If M be the quantity of water evaporated in pounds, V the issuing velocity in feet per second, this living force will be

$$M \frac{V^2}{2\ g.}$$

The work expended to produce the velocity V, in the mass M, may be represented by a constant force acting through a given height, $P\ h = M\frac{V^2}{2\ g.}$; P. h. being represented in foot pounds. For the work performed by the boiler in one *minute* we have $60 \times P.\ h. = 60\ M.\frac{V^2}{2\ g.}$ and if we represent by M^1 the weight of water, in pounds, evaporated and forced out of the orifice in *one minute*, we have $M^1 = 60$ M.

and

$$60,\ P.\ h. = M^1\frac{V^2}{2\ g.}$$

If we suppose h to be one foot, and divide by 33.000, we have $\frac{60.\ P}{33.000} = \frac{M^1\ V^2}{2.g.\ 33.000} = N, =$ the number of horse power of the boiler.

Prof. Zeuner furnishes a table of values of the velocity V, in metres per second, for different pressures, from 2 atmospheres, to 14 atmospheres, which is given below.

The velocities V, for different pressures, taken from Zeuner's table, are as follows:

For 2 atmospheres	..........................V =	481.71	metres per	second.
3 "	....	606.57	"	"
4 "	....	681.48	"	"
5 "	....	734.32	"	"
6 "	....	774.89	"	"
7 "	....	807.57	"	"
8 "	....	834.90	"	"
9 "	....	858.33	"	"
10 "	....	878.74	"	"
11 "	....	896.80	"	"
12 "	....	913.00	"	"
13 "	....	927.69	"	"
14 "	....	941.06	"	"

From this table the corresponding values of $\frac{V^2}{2.\ g.\ 33.000}$ in English units, have been deduced, and we have the very simple results in the following table for finding the total theoretical horse power of any boiler.

TABLE FOR FINDING THE HORSE POWERS OF BOILERS.

Pressure in Boiler, in Lbs. per Square Inch.	Horse Power = the numbers of this table multiplied by M^1 water evaporated per minute, in lbs.	Pressure in Boiler, in Lbs. per Square Inch.	Horse Power = the numbers of this table multiplied by M^1 water evaporated per minute.
14.7	$0.0 \times M^1$	110	$3.43 \times M^1$
20	0.5	115	3.52
25	0.9	120	3.59
30	1.60	125	3.65
35	1.45	130	3.72
40	1.65	135	3.79
45	1.85	140	3.85
50	2.05	145	3.92
55	2.23	150	3.97
60	2.35	155	4.02
65	2.52	160	4.06
70	2.65	165	4.12
75	2.82	170	4.18
80	2.87	175	4.23
85	3.00	180	4.27
90	3.09	185	4.32
95	3.19	190	4.36
100	3.28	195	4.39
105	$3.37 \times M^1$	200	$4.40 \times M^1$

To use this table, find the weight of water evaporated in each *minute* by the boiler, in pounds, and multiply the number expressing this weight by the number in the table corresponding to the pressure in the boiler; the product will be the total disposable power of the boiler.

This new expression for the disposable power of boilers was deduced incidentally by Prof. Zeuner as the disposable power of the steam after it enters the cylinder of the engine, and he found its equivalent in an expression previously determined for the living force of the steam issuing at a high velocity into the atmosphere through a small orifice.

The value of this rule consists in the facility with which it may be employed, its absolute correctness, and the readiness with which the performance of an engine which utilizes all the steam produced by a given boiler may be compared with a perfect working engine, the standard being from 50 to 60 per cent. of the horse power of the boiler. A higher efficiency than 60 per cent. cannot probably be looked for in practice with a high-pressure engine, as at present constructed. A perfect working engine may also, conversely, be an approximate test for the economic performance of a given boiler.

According to determinations of Prof. Zeuner, based exclusively on the dynamic theory of heat applied to the problem of the efficiency of ordinary high-pressure engines, the utmost efficiency possible, under the most favorable conditions of expansion, is from 50 to 60 per cent. of this theoretical power; the 40 to 50 per cent. loss being inherent in the nature of the engine, which no improvement can greatly alter.

The following test of this theoretical law, and of the new rule for the disposable power of boilers, is derived from the preceding tables of engines. Taking, for comparison, engines working under steam at 80 pounds pressure, cutting off at ¼ of the stroke, and making 60 revolutions a minute, we find for engines of 10, 20, 30, 40, &c., horse powers the quantity of water required per minute from the tables, which are based on actual experiments. These quantities are introduced in the following table in the first column; the second column showing the disposable horse powers of the boilers which produce exactly those quantities of steam; the third column shows the actual horse powers corresponding for the steam which enters the cylinder, according to Mr. Emery's experiments. The efficiency of the smaller engines is placed at 53 per cent., and of the larger at 60 per cent., the intermediate powers ranging from 53 to 60.

If in each case we have a boiler which will evaporate just the quantity of water given in the first column, we may find the theoretical disposable power of these boilers by the preceding rule of horse powers of boilers, which should correspond with the results of experiments.

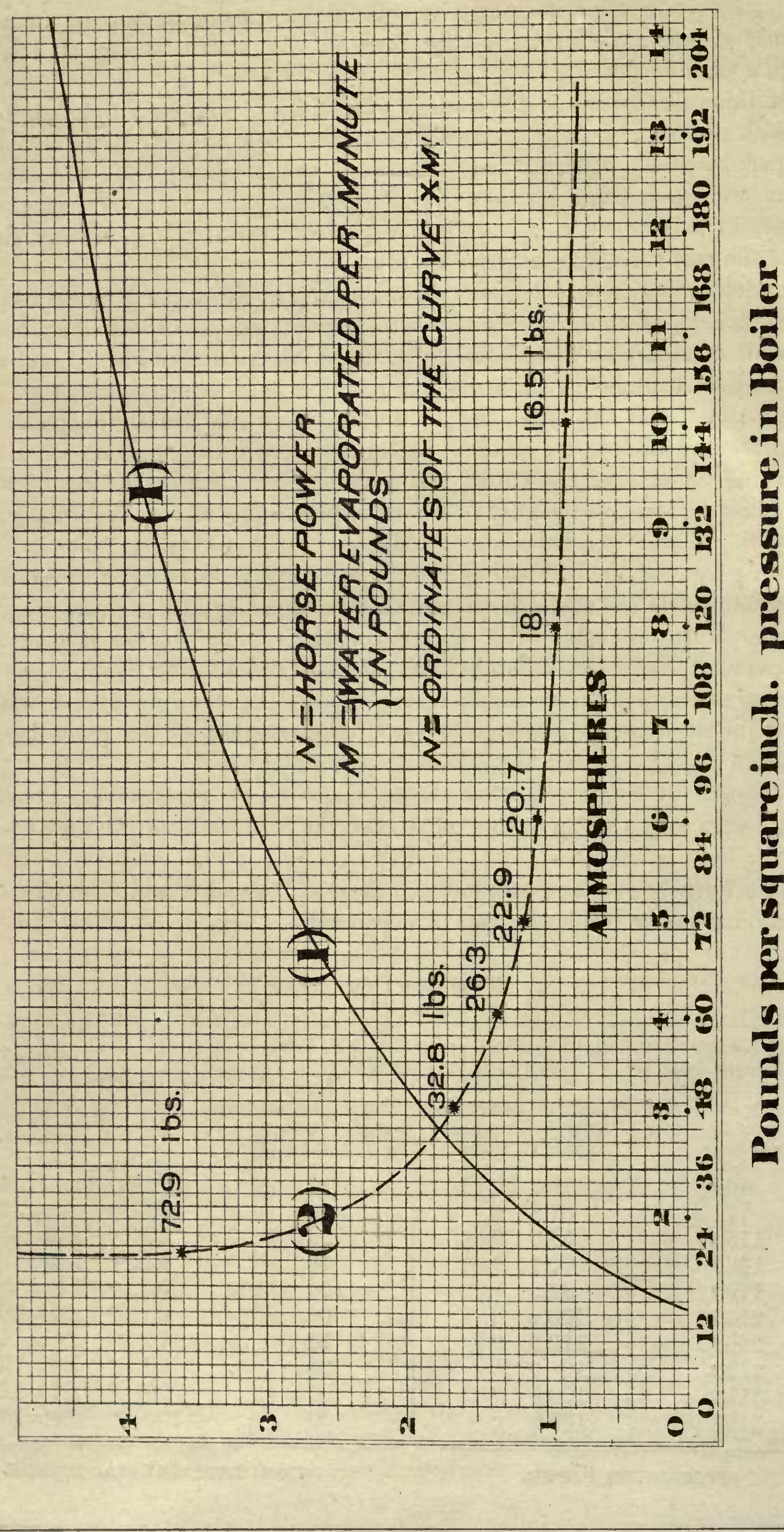
The results are given in column four of the table, showing a remarkable coincidence. The accuracy of the experimental results in the steam engine tables, and the correctness of the theoretical laws, thus confirm each other.

These examples have been taken at random. A more extended and thorough comparison might be made for engines working under various degrees of expansion.

Table of Comparison.

Pounds of water which passes through cylinder of Engine = Pounds of water evaporated by Boiler per hour.	Total disposable power of Steam at 80 lbs. pressure. N = horse power from Table = Disposable power of Steam.	Actual H. Power by indicator, from Tables of Engines Using amounts of water in first column with 80 lbs. p. cutting off at ¼.	Theoretical disposable power of the same steam after it enters the cylinder.
400	19.3 H. P.	10	=10 Div'd by ,53= 19.0 H.P.
771	37.3 "	20	20 " ,53= 36.4
1159	56.0 "	30	30 " ,53= 54.5
1460	70.1 "	40	40 " ,53= 70.8
1790	86.5 "	50	50 " ,56= 87.7
2136	103.2 "	60	60 " ,56=102.5
2469	119.3 "	70	70 " ,56=117.4
2790	134.9 "	80	80 " ,56=133.7
3113	150.5 "	90	90 " ,56=148.7
3424	165.5 "	100	100 " ,60=166.6
FROM BOILER POWER.		FROM EXPERIMENTAL ENGINE.	

DIAGRAM OF HORSE POWER OF BOILERS (CURVE 1)



Explanation of the Diagram of Horse Power of Boilers.

This diagram is constructed from the table for finding the horse powers of boilers, or from the formula $N = \frac{V^2}{2.g. 33.000}$ the velocities being taken from Zeuner's table and reduced to English units.

The formula shows that the curve which indicates the powers of the same boiler with increasing pressures of steam, is a common parabola. In the diagram the same boiler may be supposed to be used with steam pressure increased according to the numbers along the line of abscissas; and supposing the same quantity of steam M^1 to be evaporated each minute, which will be approximately true, the ordinates of the curve show the increase of disposable power of the boiler, as the pressure is increased.

The curve of boiler horse-power, curve (1), supposes the evaporation constant, under different pressures, and exhibits the law of increase of disposal power as the pressure rises. An increase of power would also attend increased evaporation.

The quantity of water or steam in pounds required for a theoretically perfect engine, that is, an engine which, for instance, would utilize *all* the disposable work of a boiler, is given by Prof. Zeuner in the following table, taken from his work, the numbers being reduced to English units.

Quantity of Vapor expressed in Pounds required in a Theoretically Perfect Engine to produce one Horse Power per Hour.

Tension of the Vapor in Atmosphere.	Pounds of Water for One horse power per hour.
1½	72.9
3	32.8
4	26.3
5	22.9
6	20.7
8	18.0
10	16.5

Putting these numbers in the form of a curve, they are represented by curve (2) of the preceding diagram.

This curve exhibits to the eye the rate of diminution of the quantity of steam required in a *perfect* engine to produce one horse power per hour under the different pressures given on the line of abscissas.

The lower curve (2) may be taken to represent, in a general way, the diminution of the size of the boiler required for a *perfect* engine, as the pressure rises. And the two curves taken together show the fallacy of estimating the horse power of the boiler by heating surface alone, or without reference to quantity of water evaporated, pressure, &c.

The efficiency of real engines may be found, in a general way, from curve (2), or by the table from which it is derived, by taking double the quantities of water as the amount required for any given pressure, when the steam is utilized under the most favorable conditions.

The Evaporative Power of Boilers.

The quantity of water evaporated by a given boiler in an hour, depends not only on the heating-surface and the proportions of the grate-surface, heating-surface, and draft area, but also upon the quantity of air which passes through the furnace in a given time. A locomotive boiler, for instance, burning ten pounds of coal on each square foot of grate-surface in an hour, will evaporate about nine pounds of water for each pound of coal, under the most favorable conditions. The same boiler, running at high speed and burning seventy-five pounds of coal on each square foot of grate-surface, will evaporate seven pounds of water *for each pound* of coal burned. The total quantity evaporated in an hour in the first case will be $10 \times 9 = 90$ pounds of water for each square foot of grate surface; and in the second case, the same boiler, under a forced draft, will evaporate $75 \times 7 = 525$ of water in one hour. Here there is a vast difference in the total amount of evaporation; but each pound of coal, under the forced draft, produces less steam, in the proportion of 7 to 9 pounds; so that while the economy of fuel in one sense is less, the total amount of work done by the same boiler in the same time is very much greater with the higher rate of combustion.

The same differences occur in stationary boilers having the same general proportions, but different heights of chimneys. The chimney is the machine or agency which produces the flow of air through the furnace, and which, by its height, determines the quantity which passes through in a given time. It is, therefore, the principal element in the determination of the total evaporation of a boiler in a given time.

There are probably no phenomena connected with the generation and utilization of steam so imperfectly defined, either theoretically or practically, at present, as those connected with the quantity of air which passes through the furnaces of boilers, under varying conditions of draft, and the *temperatures* of the furnace and flues which depend on this quantity. And hence, for greatly varying heights of chimneys, the quantity of coal consumed per hour can only be determined in advance by the most uncertain estimates. It has been generally assumed from the experiments of Prof. Johnston, Mr. Hunt, and others, that in ordinary practice double the amount of air necessary for complete combustion passes through the furnace. It is contended, on the other hand, by Rankine and Clarke, that for high rates of combustion this law is not true; and experiments made at the Paris Exposition, in which the quantity of air was *measured*, in different cases, show that in ordinary practice this law of double the quantity is by no means to be relied on. Hence all attempts to reduce the laws of evaporation of boilers to fixed and definite rules of practice for all conditions of draft, have thus far been based on assumptions which have no definite and precise foundation in practice.

For stationary and steamship boilers the chimneys are generally of a uniform height, arising from the nature of the structures with which they are connected, and hence the approximate amount of combustion on a square foot of grate-surface, and the resulting evaporation of water per hour, are pretty well known from practical observations. The tables of evaporation given on page 31 have been determined from such considerations, and are not intended to represent what the boilers there given might accomplish, under various rates of combustion arising from greatly varying heights of chimneys.

Experiments are greatly needed to determine the rates of combustion for varying dimensions of chimneys, as well as the quantities of air actually drawn through the furnaces under these varying rates of combustion. Such determinations are necessary in order to establish the corresponding temperatures of the furnaces and the gaseous products of combustion, and from these, the laws of transfer of heat by radiation and contact in the furnaces and flues respectively.

Boiler Explosions.

The risk of life and property involved in the use of the Steam Boiler is still, as it has always been, a source of constant anxiety to the Engineer and to the public. Explosions continually take place under circumstances of the utmost apparent security. Occurring without warning, and occupying but an instant of time, it is generally difficult, if not impossible, except in rare instances, to ascertain with certainty their true cause. There is seldom a unanimous opinion on the part of experts who examine into the causes after the event.

The following remarks on the subject are intended, therefore, to point out, as far as possible, some of the obvious sources of danger, which are clearly indicated by the developments of the Dynamic theory of heat, and confirmed by actual experiments. The results will serve, perhaps, to indicate more clearly the direction in which further experiments are needed.

Explosion can occur from two causes only—first, from deficiency of strength in the shell or other parts of a boiler. This deficiency of strength may be an original defect arising in the material or workmanship at the time of construction; or it may be due to deterioration from use, from ordinary wear, or from injuries occurring from mismanagement, want of attention and repairs, etc. Manufacturers and Engineers are supposed to comprehend fully these causes of danger, and ought to be able to avoid them.

The other source of danger arises from an accumulation of pressure within the boiler, to a dangerous degree above that which the structure is designed to resist. This accumulation of pressure may be *gradual*, and due simply to the increase of pressure which attends a continued evaporation when there is not sufficient outlet for the steam constantly formed. This source of danger will first be discussed.

One question to be solved is at what rate, in time, will the pressure in *any given boiler in active use* increase if there is no outlet for the steam. In other words, how long a time must elapse before the pressure under such circumstances will rise from an ordinary working pressure to a dangerous or prohibited pressure.

This is a practical question, and its solution ought to point out the degree of watchfulness necessary on the part of an engineer. It has been solved in a very thorough and practical manner by Mr. Zeuner, in the work to which reference has been made.

The formula which is given below is Prof. Zeuner's formula derived, not from experiments, but in an incidental manner from a mathematical discussion of the laws of temperature, pressure, and volumes of vapors, based on Regnault's experiments.

Let

T be the time in minutes which must elapse from the instant that all egress of steam is prevented in a boiler (by the stopping of the engine and closing of the safety-valve) to the instant when a dangerous or bursting pressure must follow in the boiler.

W Represent the weight of water in the boiler.

t_1. The temperature of the water due to the dangerous pressure.

t. The temperature due to the working pressure.

Q The quantity of heat in units of heat transferred to the water per minute.

Then

$$T = \frac{W\ (t_1 - t)}{Q}$$

the mean specific heat of water being taken as unity.

This formula shows that the time, T, is greater the greater the amount of water in the boiler, and it diminishes as Q increases. T is less also as $(t_1 - t)$ is less. At high pressures a greater change of pressure accompanies a small change of $(t_1 - t)$, and T will fluctuate more rapidly at high pressures than at low pressures.

The following examples, as illustrations, will exhibit the applications of the formula :—

EXAMPLE 1.

A Marine Tubular Boiler of the Largest Size.

W=79,000 lbs. of water.

Suppose the working pressure to be 2½ atmospheres, and the dangerous pressure 4. atmospheres,

$$(t_1 - t) = 29° \text{ Fahr.}$$

The boiler contains 5,000 square feet of heating surface, and supposing the evaporation to be 2.5 lbs. per hour for each square foot of heating surface, we have,

$$\text{Q in pounds of water per minute} = \frac{5{,}000 \times .2.5}{60}.$$

And taking as a sufficient approximation 1,000 units of heat as the equivalent of the evaporation of 1 lb. of water, we have,

$$\text{Q in units of heat} = \frac{5{,}000 \times .2.5. \times 1{,}000}{60.}$$

These numbers introduced into the formula give,

$$T = \frac{79{,}000 \times 29°}{\dfrac{5{,}000 \times .2.5. \times 1{,}000}{60}} = 11 \text{ minutes.}$$

Hence the steam would reach a dangerous pressure in 11 minutes.

EXAMPLE 2.

A Return Tubular Boiler, containing 3,000 lbs. of water, and having 500 square feet of heating surface, each square foot evaporating, as before, $2\frac{1}{2}$ lbs. of water.

Suppose the ordinary working pressure to be 75 lbs., and the dangerous pressure to be 150 lbs. per square inch.

The formula gives,

$$T=7 \text{ minutes.}$$

EXAMPLE 3.

A Locomotive Boiler, containing 5,000 lbs. of water, and having 11 square feet of grate surface, and burning 100 lbs. of coal on each square foot of grate an hour. Each pound of coal will, under such conditions, evaporate about 7 lbs. of water.

Suppose the working pressure to be 100 lbs., and the dangerous pressure to be 200 lbs. per square inch. The transition from the working to the dangerous pressure will occur in

$$T=2 \text{ minutes.}$$

This example is, of course, an impossible case, because no locomotive standing still can burn 100 lbs. of coal on a square foot of grate in an hour. It illustrates, nevertheless, the degree of danger under circumstances which may occur. For if we suppose this locomotive standing still to burn only 10 lbs. of coal per hour on each square foot of grate, the time T will be increased ten times, and we will have,

$$T=20 \text{ minutes.}$$

EXAMPLE 4.

The Steam Fire Engine. Taking an actual case. The boiler contains 338 pounds of water, and it has 157 square feet of heating surface.

Supposing each square foot of heating surface to generate 1 pound of steam in one hour, the pressure will rise from 100 to 200 pounds in

$$T=7 \text{ minutes.}$$

EXAMPLE 5.

To find in the same boiler how long a time will be required to *get up steam.* That is to run the pressure from 0 to 100 lbs.

If we suppose only $1\frac{1}{2}$ cubic feet of water to be introduced into the boiler at first, we shall have

$$T = \frac{93 \times 117}{\frac{157 \times 1000}{60}} = 4.1 \text{ minutes.}$$

This result is realized in practice, and exhibits the truth of the formula.

The formula shows generally that boilers which contain large quantities of water and burn coal slowly, have less rapid fluctuations of pressure. And also that the lowering of the water in the boiler from failure of the feed apparatus, by diminishing W, diminishes also T in the same proportion.

Low water increases the danger of explosions, therefore, not only by exposing plates to overheating, followed by a sudden evolution of steam, but by diminishing the ratio $\frac{W}{Q}$. It is even probable that Q is largely increased in such cases by internal radiation of heat from the plates to the water.

SAFETY VALVES.

It is supposed that a *gradually increasing* pressure can never take place if the safety valve is in good working order, and if it have proper proportions. Upon this assumption, universally acquiesced in, when there is no accountable cause, explosions are attributed to the "sticking" of the valves, or to "bent valve stems," or "inoperative" valve springs. As the safety valve is the sole reliance in case of neglect or inattention on the part of the engine driver, it is important to examine its mode of working closely.

It is designed on the assumption that it will rise from its seat under the statical pressure in the boiler, when this pressure exceeds the exterior pressure on the valve, and that it will remain off its seat sufficiently far to permit all the steam which the boiler can produce to escape around the edges of the valve.

The problem to be solved is, then, to find first what amount of free orifice is necessary for the flow of steam from a given boiler under a given pressure, and then to ascertain whether ordinary valves will rise far enough to give this amount of free orifice.

The ordinary safety valve, as at present constructed, consists of a disc which closes the outlet of a short pipe leading from the boiler. The area of the disc or diameter of the valve is usually determined from theoretical considerations based on the velocity of the flow, or upon the results of experiments made to ascertain the area of orifice necessary for the flow of all the steam a boiler can produce under a given pressure. The fact is recognized by engineers and constructors, that the real diameters of safety valves must be greater than the theoretical orifices, because common observation shows that the valves do not rise appreciably from their seats; and to make the outlet around the edges of the valve equal in area to the pipe, the valve should rise $\frac{1}{4}$ of its diameter.

The uncertainty begins when it is attempted to fix upon a diameter. The difficulties of the problem become evident in the light of late experiments.

In regard to the area of orifice necessary, this question is solved by Prof. Zeuner in a very simple manner theoretically; the following table gives the results of his determinations reduced to English units.

Let d be the diameter of the orifice in inches, and w the weight of steam which flows through the orifice in a second (equal to the weight of water evaparated in a second) in the problem under consideration; then the diameters d for different pressures are found from the following table.

For 2	atmospheres	$d = 1.72\sqrt{w}$.	For 9	atmospheres	$d = 1.22\sqrt{w}$.
3	"	$d = 1.51\sqrt{w}$.	10	"	$d = 1.21\sqrt{w}$.
4	"	$d = 1.41\sqrt{w}$.	11	"	$d = 1.19\sqrt{w}$.
5	"	$d = 1.35\sqrt{w}$.	12	"	$d = 1.18\sqrt{w}$.
6	"	$d = 1.30\sqrt{w}$.	13	"	$d = 1.17\sqrt{w}$.
7	"	$d = 1.28\sqrt{w}$.	14	"	$d = 1.16\sqrt{w}$.
8	"	$d = 1.22\sqrt{w}$.			

The following Table gives the results of experiments made at the Novelty Iron Works in New York City, several years before Prof. Zeuner's work was published. These experimental results have never before been published. The observations were made with great care, with a tubular boiler adapted to the experiments.

The first column gives the pressure in pounds per square inch in the boiler, and the second the area of orifice in square inches for each square foot of heating surface of the boiler.

Pressure in the Boiler in pounds above the atmosphere.	Area of Orifice in square inches for each square foot of heating surface.
0.25	.022794
0.5	.021164
1.	.018515
2.	.014814
3.	.012345
4.	.010582
5.	.009259
10.	.005698
20.	.003221
30.	.002244
40.	.001723
50.	.001398
60.	.001176
70.	.001015
80.	.000892
90.	.000796
100.	.000719
150.	.000481
200.	.000364

To compare the results of Zeuner's formula, which is entirely theoretical, with the results of these experiments, we may assume that each square foot of heating surface of a tubular boiler will evaporate 2.5 pounds of water per hour with ordinary chimney draft. Taking a series of boilers of the different heating surfaces named below, the comparison is given for two pressures, 3 and 5 atmospheres.

3 ATMOSPHERES.			5 ATMOSPHERES.		
HEATING SURFACE, SQUARE FEET.	AREA OF ORIFICE BY EXPERIMENT.	AREA OF ORIFICE BY FORMULA.	HEATING SURFACES IN FEET.	AREA OF ORIFICE BY EXPERIMENT.	AREA OF ORIFICE BY FORMULA.
	SQUARE INCHES.	SQUARE INCHES.		SQUARE INCHES.	SQUARE INCHES.
100	.089	.09	100	.12	.12
200	.180	.19	200	.24	.24
500	.45	.48	500	.59	.59
1000	.89	.94	1000	1.20	1.18
2000	1.78	1.90	2000	2.40	2.37
5000	4.46	4.75	5000	6.00	5.95

At five atmospheres pressure the results from the two sources are almost identical, and at 3 atmospheres sufficiently near to make a remarkable coincidence. The formula of Mr. Zeuner is, however, preferable in practice, as it takes account of the *weight of water evaporated*, which depends on the *amount of fuel burned* (*height of chimney*, *&c.*) and is therefore more comprehensive.

The mode of determining the area of free orifice necessary for the flow of steam may thus be considered theoretically and practically settled.

The next question for consideration is, how High will any safety valve rise under the influence of a given pressure? This question cannot be determined theoretically, except that it has been demonstrated by Zeuner, Weisbach, and others, that as soon as the flow of steam begins the pressure in the plane of the orifice rapidly diminishes, and in fact ceases at a minute distance from the orifice, and is also diminished within the orifice, in the pipe. It has been supposed that the force of the issuing steam striking against the lower face of the valve may act to keep it off its seat.

This question has been settled conclusively by Mr. Burg, of Vienna, an account of whose experiments was published in the proceedings of the Vienna Academy of Sciences in 1862. Mr. Burg made careful experiments to determine the actual rise of safety valves above their seats. He found by actual measurements, made by means of apparatus constructed for the purpose, that an ordinary four-inch valve rises according to the laws stated below. For a boiler pressure of

lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
12	20	35	45	50	60	70	80	90

The rise of the valve is, in parts of an inch,

$\frac{1}{36}$	$\frac{1}{48}$	$\frac{1}{54}$	$\frac{1}{65}$	$\frac{1}{86}$	$\frac{1}{86}$	$\frac{1}{168}$	$\frac{1}{132}$	$\frac{1}{168}$

Or, taking average valves, the rise for pressures from 10 to 40 lbs. is $\frac{1}{40}$ of an inch, from 40 to 70 lbs. $\frac{1}{80}$, and from 70 to 90 lbs. $\frac{1}{120}$ of an inch.

These results show that the rise *diminishes* rapidly, as the pressure increases—a result which is indicated by theory. The very small rise for pressures from 70 to 90 lbs., $\frac{1}{120}$ of an inch, is remarkable.

If now we take a tubular boiler with 500 square feet of heating surface, the free orifice necessary for the flow of all the steam the boiler can produce at 5 atmospheres pressure will be, according to Zeuner's Formula, $\frac{59}{100}$ of a square inch. Let x be the diameter of the valve, which, by rising $\frac{1}{120}$ of an inch, shall give this amount of free orifice. The circumference will be approximately $3x$, and we must have $3x. \frac{1}{120} = .59$ square inches, from which we find the diameter of the required valve,

$$x = 23.6 \text{ inches.}$$

This is an impracticable size. If we assume a size of six inches diameter as suitable, and ascertain how high the valve must rise to make an annular opening around the edge equal to .59 of an inch, we may let x represent the rise of the valve. The circumference will be, in round numbers, $3 \times 6 = 18$ inches, and we will have $18 \times x = .59$ square inches; $x = \frac{1}{33}$ of an inch. This amount of rise appears clearly impossible from the results of Mr. Burg given above, as the valve will rise under 5 atmospheres only $\frac{1}{120}$ of an inch.

These results have been confirmed in another manner. *Baily*, in experimenting with his volute springs, found that, for an ordinary locomotive, a valve of 13 inches diameter was required, and with this the pressure in the boiler rose considerably above the pressure at which the valve was set. With ordinary valves he found that there was no relief of the boiler when the fires were kept in full blast. Gooch, the English engineer, recommended three safety valves to each locomotive. And Mr. Holley, in his recent work on Railway Practice, recognizing the inefficiency of the ordinary valve, states that he has seen the pressure in a locomotive boiler rise to 140 lbs., with two valves blowing off at 100 lbs.

These facts and expressions from practical engineers are sufficient to confirm the foregoing deductions.

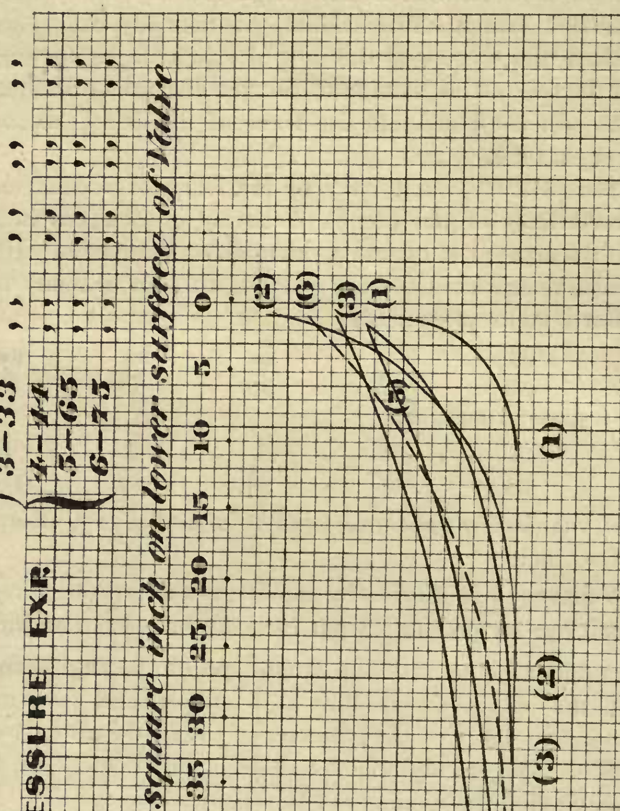
Another series of experiments, made by Mr. Burg, is still more conclusive, and justifies him in the statement that the "most *incomprehensible delusion* has existed in regard to the efficiency of the valve, as commonly employed;" and that it acts at most only as an alarm, but cannot be depended on as security against explosions.

His final experiments were made with a view of determining the pressure in pounds per square inch actually exerted upon the under surface of the valve, with different amounts of rise or lift, and were intended to supplement the first experiments.

DIAGRAM

SHOWING THE RISE OF SAFETY VALVES.

(DEDUCED FROM BURG'S EXPERIMENTS)



He constructed an apparatus by which he was enabled to remove weights from the exterior load on the valve at the same time that he measured, by the revolutions of a screw, very accurately, the corresponding rise.

The results are given in the following diagrams, which have been made from his published records. Six experiments were made, in which the pressure of steam in the boiler was first taken at 10 English lbs.; then at 27; again at 33, 44, 65, and 75 lbs. The results correspond to the numbers 1, 2, 3, 4, 5, 6, in the diagrams.

At the beginning of each experiment the valve was loaded to resist the required pressure in the boiler. The curves 1, 2, 3, 4, 5, 6, represent the rising of the valves, during each series, as weights were taken off the the valve. The horizontal line of numbers, 0, 5, 10, 15, &c., gives the actual pressures on the lower surfaces of the valve in pounds per square inch for the rise of valve, as shown by projecting the number down to the corresponding curve.

Thus, in the first experiment, beginning with ten lbs. constant pressure per square inch in the boiler, the rise (curve (1)) was zero; by removing weights, $\frac{1}{2}$ lb. at a time, the valve rose according to curve (1), the height from the base line, 0, 0, 0, being in lines, or $\frac{1}{12}$ of an inch. With a rise of $1\frac{1}{2}$ lines, for instance, the pressure on the lower surface of the valve was only 5 lbs., and with a rise of 1.9 lines (about 2 lines, or $\frac{1}{6}$ of an inch), the pressure on the lower surface of the valve was less than 1 lb. per square inch.

Taking the fifth series of experiments, with a constant boiler pressure of 65 lbs., it is seen by curve 5 that a reduction of pressure to 35 lbs. (by unloading the valve), was necessary, in order that the valve might rise $\frac{4}{10}$ lines, or $\frac{1}{30}$ of an inch.

In all the experiments a rise of two lines, $\frac{1}{6}$ of an inch, as shown by the curves, was only accomplished by diminishing the load on the valves, until the pressure on the under surface was reduced to *less than 7 lbs.* per square inch.

These remarkable results show that when a valve stands from its seat the very small distance of $\frac{1}{6}$ of an inch, there is practically *very little sustaining* force in the current of outflowing steam. They confirm the former results that, to obtain a rise of valve above the minimum height of $\frac{1}{120}$ of an inch for high pressures, an increasing pressure within the boiler is not sufficient. On the contrary, a diminution of exterior load on the valve is indispensable.

These results show conclusively that the ordinary safety valve presents no real security. If the fires are kept up, and no other relief afforded than the self-action of the valve, the pressure on the boiler must continue to rise,* and a few minutes inattention on the part of an engineer may result in an explosion. It is not necessary to such a result that the valve should "stick," or that the stem should "be bent," for it is proved beyond a doubt that the *higher the pressure*, the *less will the valve rise;* and in not rising it simply obeys the action of the forces exerted upon it.

Explosions arising from Sudden Evolutions of Steam.

A *gradually increasing* pressure to a dangerous degree would be impossible in any boiler, if the safety valve were what it is supposed to be, viz., a perfect automatic means for liberating all the steam which a boiler may produce with the fires in full blast, and all other orifices for the escape of steam closed. Until such a safety valve shall have been devised and adopted into general use, safety from gradually-increasing pressure must depend on the attention and watchfulness of the engineer alone.

There are supposed to be, however, occasional instances of sudden or violent evolution of steam, in such quantities that no relief is possible through the medium of safety valves, however perfect they may be in their functions.

* The formula for diameter of orifice shows that the free orifice *necessary* for the issue of steam diminishes but slowly as the pressure rises.

That such occurrence may take place from natural causes, which do not require for their explanation any extraordinary hypotheses, such as chemical decomposition or electrical action, may perhaps be demonstrated. But there is reason to believe that they are exceedingly rare.

One of these causes which has received the most general acceptance, both in theory and practice, is the sudden flow of water upon plates which have become overheated by the accidental lowering of the water level in the boiler. It is, in fact, considered almost an axiom that very low water will cause an explosion.

There is no doubt that exposure of the upper surfaces of flues, or the crown of a furnace, to the intense action of heat, when there is no water upon their surfaces to absorb or transfer this heat, is highly injurious and destructive to the boiler; and on this ground alone all the devices for regulating or observing the water level are necessary and advisable. It is not certain, however, that even in such an extreme case of accident or neglect as overheated plates, an explosion must ensue if there be an efficient safety valve.

If we suppose ten square feet of the furnace or flues to become heated to redness, say 1,000 degrees (a very extreme case), the quantity of heat in units of heat which would be transferred quite suddenly but not necessarily instantaneously, to water coming in contract with them at the ordinary boiler temperature, would be found thus: 10 square feet of iron, $\frac{1}{4}$ of an inch thick, would weigh about 100 lbs. The specific heat of iron is .11; and if we take 300° as the temperature of the steam of the boiler, the lowering of temperature of the plates would be $1{,}000° - 300° = 700°$, and $100 \times 700 \times .11 = 7.700$ units of heat. This amount is sufficient to evaporate about 7.7 lbs. of water.

If we refer to any of the examples of the application of the formula,

$$T = \frac{M\ (t_1 - t_2)}{Q}$$

we will find that to raise the pressure from an ordinary working pressure to a dangerous pressure, a much greater number of units of heat was required, 6. The quantity of heat transferred to the boiler in each *minute* was, in the examples given, as follows, respectively:

Example 1,	208,300
2,	20,830
3,	123,300

From these examples it is seen that the addition of only 7.700 units of heat, either gradually or suddenly, would not cause a dangerous elevation of pressure in the boiler, under the conditions assumed.

Nothwithstanding, therefore, the overheating of plates is highly detrimental, and no doubt dangerous, yet it seems probable that this source of danger of explosions belongs to the dangers from gradually-increased pressure, and may be avoided by perfectly efficient safety valves.

The occurrence of this cause of danger can only happen from the most culpable neglect or inattention, and cannot be regarded as an unforseen danger, since the means of warning are abundant.

The principal cause of *sudden evolution* of steam, which finds an explanation in the known properties of water, and its action under changes of temperature, is probably what is called *concussive ebullition.* This is doubtless a real danger, and the more so because it is hidden, and gives no warning. How far this phenomenon takes place in steam boilers, and produces explosions, there are no means of knowing. But that it is a *possible* cause, there seems to be good reasons for believing.

It is known from the investigations on the boiling points of water, and other fluids, by Dufour, Kopp, Donny, and others, that the conversion of water into vapor at a certain temperature due to the pressure is dependent on other conditions besides the temperature; that water may become heated, under certain conditions, to temperatures many degrees above the temperature due to its boiling point.

The phenomenon called "concussive ebullition" arises, according to Dufour, from the principle that in order that a liquid may be transformed to vapor at any temperature, some portion of the surface must be freely exposed to a space into which the vapor may expand. This was demonstrated by suspending drops of water in heated oil. The temperature of the water was raised considerably above the boiling-point without the formation of vapor; but if a bubble of air or a piece of porous substance was placed in contact with the water, a burst of vapor occurred. Professor Donny, of Ghent, observed that water thoroughly *deprived of air*, and sealed up in thin glass tubes, free from air, and heated at one end of the tube, could be heated to 280° F., under atmospheric pressure. The burst of vapor, when it took place, threw the whole mass of water suddenly to the other end of the tube.

This phenomenon of concussive ebullition may be produced in a variety of ways in the chemical laboratory, and accompanies the processes for the rectification of sulphuric acid to such an extent that special means are required to avoid its evil effects.

The practical conclusion to be derived from these facts in connection with the generation of steam in steam boilers, is that the water in a boiler may, under some circumstances—such as slow-continued evaporation when a boiler is at rest, or doing no work—be nearly deprived of air, and the circulation being then feeble, portions of the water in contact with the plates may become heated to a higher temperature than that of the mass of water above.

Under such circumstances the sudden starting of an engine, or other cause of agitation, producing an increased circulation and an agitation of the water, might cause a sudden evolution of steam in such quantities and with such force as not only to produce a dangerous and sudden elevation of pressure, but a violent concussion, by throwing large masses of water against the sides of the boiler.

It was demonstrated by Dufour and others, that the presence of air in minute bubbles prevented this overheating of portions of the water, and caused evaporation to go on continuously. When a boiler is at work, circulation is rapid and continuous, and in most cases feed water fully charged with air continually enters the boiler; and hence the conditions necessary to cause a retarded ebullition are rare.

On this subject, however, further experiments and investigations are especially needed.

The general conclusions which may be regarded as established from experiments, observations, and practice, thus far seem to be:

1. That the laws of resistance of the parts of boilers to the internal pressure are sufficiently well established.

2. It is of the utmost importance that the materials employed should be of the best quality as regards strength and durability; and as there are but few manufacturers of boiler plates, the inspection of materials especially boiler plate, should be made by the government *at the place of manufacture*, and the inspection should extend to the qualities of ores and the *process of manufacture;* the required stamps, brands, or certificates being put on or authorized by the inspector in person. There is much greater certainty of securing the best materials by an inspection of the process of working and the raw materials employed, than by an inspection of plates after they have been sent to market, when, to all external appearances, good and bad plates are not easily distinguished.

3. An inspection of the boiler during the process of construction. It is impossible to discover all the defects of construction after a boiler is made.

4. The deterioration of strength from wear and tear, from sudden heating or cooling of parts, from oxidation, &c., gives rise to evils which can only be avoided by constant attention and repairs.

5. The danger from *sudden* generation of steam in large quantities arises probably from one cause, retarded ebullition, and is less likely to occur when the boiler is at work, receiving constantly fresh supplies of water charged mechanically with air in minute bubbles. Any device which should force air in small bubbles into a boiler, would probably prevent this source of danger.

6. The ordinary construction of the safety valve is fundamentally defective, being based on ideas in regard to its action which are unsound and delusive. A safety valve should be adopted which is not dependent for its action *on the pressure of the steam at the orifice opened by the valve*, and through which the steam flows, since it is demonstrated that the pressure at this point practically ceases with any considerable opening of the orifice.

A new construction for safety-valves, suggested by the foregoing discussion, is exhibited in the following cuts.

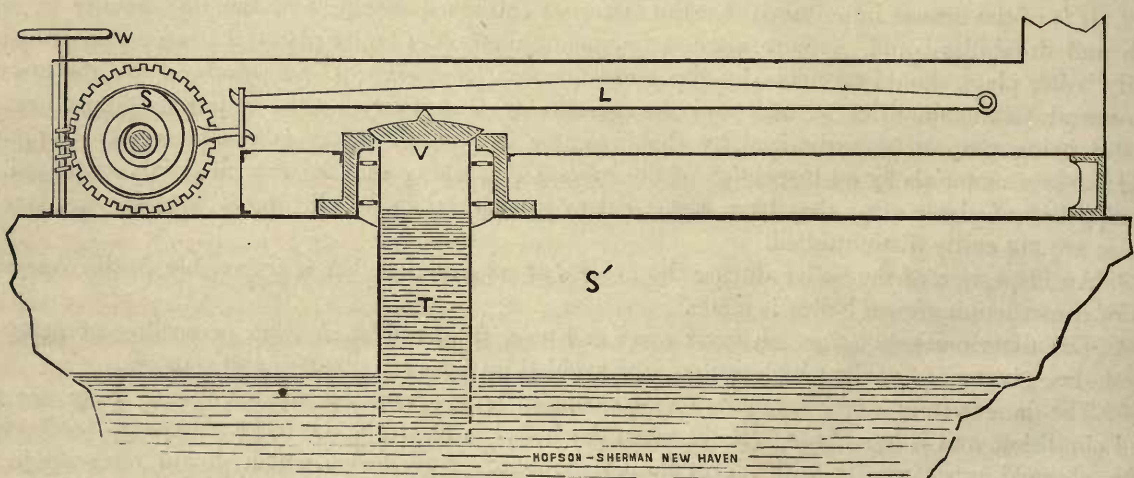
To enable a valve to rise from its seat an appreciable distance, it appears, from that discussion, that either a portion of the exterior load must be removed from the valve the moment it begins to rise, or that a continuous sustaining force must act on the valve from beneath, which shall not be diminished by the flow of steam through the orifice.

The latter expedient is adopted, and the end accomplished, by simply carrying down a stem from the valve into the water of the boiler. The total pressure of steam upon the lower end of this stem (or if it be hollow, as in the figure, upon the upper interior end surface) will be continuously exerted upon the valve. In the use of the ordinary disc or conical face valve, it has been shown that when the valve stands one-sixth of an inch from its seat the total force (or statical pressure and impulse combined) on the lower surface of the valve amounts in no case to more than five or six pounds per square inch.

If a four-inch stem be carried down below the water surface, with a pressure of 60 lbs. per square inch in the boiler, the total pressure on the lower end of the stem, transmitted to the valve, will be over 750 lbs.

This is equivalent to removing over 45 lbs. per square inch from the exterior load. With this pressure on the main surface the valve will rise from its seat, and will continue to rise as the pressure increases.

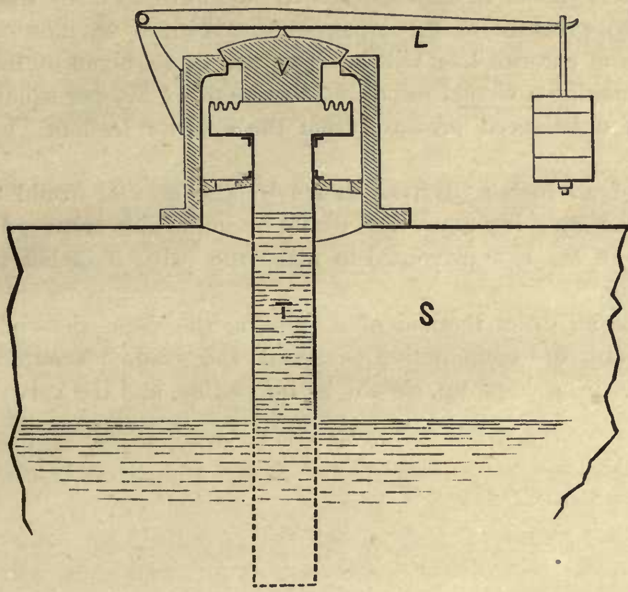
Fig. 1 represents a valve arranged for a marine boiler.



V. *Valve.* T. *Stem carried below the water.* L. *Valve lever extended into escape pipe.*

The force applied to keep the valve down is produced by a number of spiral flat springs within a barrel, adjusted by a worm and wheel. This valve can be locked, by locking the hand-wheel which turns the worm, and the worm and wheel furnishes a simple means of adjustment; all other parts are inaccessible, and the force acting on the valve cannot easily be altered by unauthorized persons.

In Fig. 2, an ordinary lever is applied with weights, and a diaphragm is acted upon by the pressure of the water in the tube or stem, the diaphragm being simply a metal plate with circular corrugations.



To calculate the size of valve for a given boiler, it is to be recollected that the circumference determines the annular opening for the efflux of steam.

Having found the area of orifice necessary by Zeuner's formula, a diameter is to be chosen, which will give this opening for a given rise; for instance one-sixth of an inch. The diameter of the stem should be less than this by one-half an inch (one-fourth all around).

The statical pressure to be applied to hold the valve down, may be calculated in the ordinary manner. The valve seat should be spherical, and the radius lever as long as convenient, in order that the valve stem may rise and fall in a true vertical line. The above described construction is simple, inexpensive, practical, and applicable to many boilers by simply putting a stem to the valves already in place.

Where the valves already in place are too far from the water, or in such a position that a stem cannot be readily extended to the water, a short valve pipe may be bolted to the boiler.

The slight agitation of the valve stem, by the currents in the boiler, will tend to keep the valve well fitted to its seat, and will prevent sticking, if there be any such tendency.

To illustrate the mode of finding the dimensions of a valve, according to this construction, let it be required to find a safety valve which shall furnish relief for all the steam which a tubular boiler of 2,000 square feet of fire surface can generate, with all other orifices closed and the fires kept in full blast. Let the pressure of steam in such a boiler be taken at 5 atmospheres.

By the table, page 42, the free orifice necessary will be 2.4 square inches.

If a valve, 4½ inches diameter, be chosen, the circumference will be approximately 14. inches, and it will be necessary for the valve to rise $\frac{1}{6}$ of an inch. $14. \times X = 2.4$ inch, $X = \frac{2.4}{14} = \frac{1}{6}$ of an inch approximately, X being the rise.

The area of the valve disc being 4½ inches, suppose a stem 4 inches diameter to be carried down below the water. The pressure on the lower part of the stem will be found by multiplying its area in square inches by the boiler pressure, or $4. \times 3.1416. \times 75. = 939$ lbs.

This would be equivalent to removing 939 lbs. from the exterior load, if the valve were of the ordinary kind, such as that used in Burg's experiments.

To this must be added the diminution of atmospheric pressure on the upper surface of the valve, which takes place when the valve rises. When the valve is seated, the atmosphere presses upon the whole surface; when it rises, only so much of this surface as is represented by the cross section of the stem, is subject to the unbalanced pressure of the atmosphere. With a $4\frac{1}{2}$ inch valve and 4 inch stem, the additional virtual diminution of exterior load will be, from this cause, about 90 lbs., and the total diminution may be taken at 1,029 lbs., making a virtual relief of pressure of 64 lbs. per square inch.

This would leave an unbalanced pressure from the exterior load of 11 lbs. per square inch, upon the area of the valve.

A rise of one-sixth of an inch nearly, as shown by the curves, would take place, and an increase of pressure in the boiler more than 5 lbs. above this would be impossible from ordinary causes.

It would be advisable in the case presented to make the valve 5 inches in diameter, and thus secure a margin for excessive firing.

This is believed to be an exact method of estimating the dimensions of valves, and one which will be borne out in practice. With the construction proposed, the gradual accumulation of pressure, with all other orifices closed and the firing kept up, should be impossible, and the valve becomes in reality a SAFETY valve.