TABLES AND DIAGRAMS RELATING TO NON-CONDENSING ENGINES & BOILERS

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RELATING TO

NON-CONDENSING

ENGINES & BOILERS

W. P. TROWBRIDGE.

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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 $2\frac{1}{2}$ miles per hour. But this fact can be expressed in another form: $2\frac{1}{2}$ 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 $2\frac{1}{2}$ 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