

*On the Absolute Power of Steam, and the most Convenient Method of Ascertaining it; more Particularly in Reference to its Effective Working, when applied Differentially in the Steam Engine, and Condensed with Hot Water.** By THOMAS PROSSER, Civil Engineer, New York.

The power of steam is to the multitude like that of some mythic gnome, unlimited; while, in the books, it is so overlaid with formula, as to be little better than a myth to ordinary engineers, who are seldom familiar with mathematical calculations, and have not the patience to await the unravelment of a long string of x's, y's, and z's. How else are we to account for the numerous inventions, even of tolerably well educated men, which promise impossibilities in the way of using steam, which promise to obtain from it more mechanical power than exists in it? There are innumerable instances of such inventions, which, had the inventors been aware of the absolute power of steam—beyond which it is impossible to go—would never have been heard of.

That the knowledge required, is in the books, may be true, but it is not made manifest, and the elaborate tables are more calculated to mystify than to place the fact in bold relief.

We are supposed to know something about the weight of water which one pound of coal will evaporate—that is something—it varies, perhaps, between 5 and 9 lbs.—not very definite truly, but according to Mr. McElroy, Vol. xxxv, p. 239, of this *Journal*, it is questionable if the range is wide enough, for, coal used for *experimental purposes*, appears not unfrequently to have been taken by the *barrow full*, for a bushel, and again transposed, and called so many pounds. 84 lbs., according to Farey, was usually considered a bushel; then it got to be 88 lbs. in calculations, and now it is 94 lbs., or somewhere between 80 and 112 lbs. Again, the evaporation of the water has usually been calculated from the capacity of the cylinder of a steam engine, which gives no record of the steam which is condensed therein. And this, then, is the *practical* way of testing the power of a steam engine and boiler—the steam being measured by the *cylinder full*, and the coals by the *barrow full*.

Now, it appears to me, that what is required is a “*standard*,” which readily conveys to the mind something definite, so far as our present knowledge extends of the absolute power of steam. For instance, one pound of water converted into steam under a certain weight, expands and lifts that weight so many times its own height. Here we have the absolute power *put into* the water to convert it into steam, and of course we can obtain no more out of it. If the height of the pound of water is one foot, then the product of the weight lifted in pounds on that “*Standard Base*,” by the height which it is carried in feet, (being equivalent to the volumes of steam which one volume of water is converted into,) gives the “*Standard Power*.” Mr. McElroy, before

* More fully explained in Volumes xxxi, xxxiii, xxxiv, and xxxv, of this Journal.

referred to, has shown how little reliance can be placed upon the Cornish pumping engine's returns of the duties of the coal. He has omitted, however, to state the expansion with which the Brooklyn pumping engine is intended to work, to give a duty of "600,000 lbs. raised one foot with one pound of coal." That knowledge is necessary, because the whole mechanical power in the steam, deducting the ordinary back pressure in the condenser, is but about equal to the effective power guaranteed, providing that one pound of coal evaporates 10 lbs. of water, which is very improbable. Even this amount of duty is but about the average reported of the Cornish engines, and some reports have even exceeded twice as much. Without knowing with what expansion the engines are worked, it is not possible to tell whether the duty reported exceeds the power of the steam or not. The tables now in use are not sufficiently correct for the purpose to which I have intimated a desire to apply them, as more than fifty years have elapsed since the experiments were made, which constitute the basis of our calculations of the density of steam. Since that time, other experimentalists have entered the same field of science, and foremost among them we place M. Regnault,* who has proved, beyond any reasonable doubt, that the whole basis is very considerably in error as regards the relations which the temperature bears to the elastic force of steam; and also, that the dilatation of dry gaseous bodies, and by inferences of dry steam also, varies from the received standard sufficiently to require the compilation of a new table, which is here presented.

The ratio of the pressure as compared with the temperature of steam, will be found to increase considerably more than the tables now in use assign, and the correctness of this position is confirmed by the experiments of Magnus. On the other hand, the dilatation is reduced by the experiments of M. Regnault. And this, together with the weight of a litre of dry air, is all the additional data which we have on which to base the new calculations. We have, therefore, nothing but the old and well-known

formula, $\left(\frac{p}{t+x}\right)$ to go by. By this the tables at present in use have been calculated, and the value of x , as obtained from the experiments of M. Gay Lussac, is 480° F., hence, $\left(\frac{p}{t+480}\right)$ 480 being the number of degrees above 32° F., to which dry air is required to be heated to double its volume.

The same formula becomes $\frac{p}{t+272.47905}$ by retaining the original basis (the centigrade) of calculation. The new table extends to the limit of M. Regnault's at the end of his ninth Memoir, and embraces each decade of the centigrade from 0° to 230° .

In addition to the temperature by the centigrade, the pressure in atmospheres, and the total heat above 0° C., I have shown the cor-

*Memoirs of the French Institute, Vol. xxi, 1845.

responding temperature, and the total heat by the Fahrenheit scale, the pressure in lbs. per square inch, and in inches of mercury.

I have also calculated by the formula before mentioned, the expansion of a volume of water at 62° F.,* by vaporization under the different pressures; also the number of cubic feet of steam required to weigh one pound.

But the most important addition, I consider to be the 8th column, which represents the duty of one pound of water just as the duty of one bushel of coal is represented by the returns of the Cornish engineers.

The "conclusion" which M. Regnault arrived at from his experiments on the dilatation of the elastic fluids, is, that, when the co-efficient of dilatation is derived from their expansion between 0° to 100° , while the elastic force remains constant, it is 0.3670, or 1 in 272.47905† for each degree above 0° C., corresponding with 1 in 490.463 for each degree above 32° F.

The same authority informs us that a litre of dry air under the ordinary pressure of the atmosphere, and at 0° C., (32° F.) weighs 1.293187‡ grammes, which gives .08063563 lbs. per cubic foot. Therefore, by calculating the decreased density of air by the law of Bogle and Marriatte, we have .0589873 lbs. as the weight of one cubic foot of air at 100° C., under the ordinary pressure of the atmosphere.

There are no reliable experiments that I know of, which give the absolute weight of steam, for although M. Regnault promised to investigate the subject, I believe that he has not yet done so; and therefore we have to resort to M. Gay Lussac's ratio of .62349, air being 1, and both at 100° C., (212° F.) at which temperature one cubic foot of steam weighs .036778 lbs.

Finally, taking the weight of 1 cubic foot of water at 62° F., at 62.321 lbs., we have 1694.48 cubic feet of steam at 212° F., produced therefrom.

And 100 cubic inches of steam at 212° will weigh 14.89849§ grains, while at 32° it will weigh .123269 grains instead of, as formerly assumed, 14.96 and .13716 grains respectively.

If this table is favorably received, I hope at some future time to extend it to every degree of the centigrade, and I cannot forbear expressing the hope that ere long no other thermometer will be in use.

If engineers, instead of taking the square inch, will take 2.31162|| square inches for the base on which the pressure of steam is measured, call it the "*Standard Base*," and say so many pounds pressure per "*Standard*," i. e., a base of water which at 62° F. weighs one pound for one foot in height, it will very much simplify calculations, and tend to give a clearer conception of some of the most important properties of steam.

*In case the new system of condensation becomes universal, and of which the writer has not the slightest doubt, the temperature of the water should be taken at 212° F., as it will always enter the boiler at about that temperature or rather above it. In this case, one cubic foot of water will weigh exactly sixty pounds, and the "standard base" will be 2.4 square inches, ($= 144'' \div 60$.)

†The experiments of M. Gay Lussac which have heretofore been accepted and relied upon, give .365, or 1 in 268.666 for each degree above 0° C., corresponding with 1 in 480 for each degree above 32° F.

‡M. M. Boit and Arago calculated this at 1.299541 grammes.

§Troy grains, of which there are 7000 to the pound avoirdupois.

|| But see a previous note, wherein 2.4 square inches is proposed.

TABLE

Of the Temperature, Elastic Force, Weight, Volume, Mechanical Power, and Total Heat of Steam for every decade of the Thermometer from 0° to 230° Centigrade.

One pound of water at 62° F., resists conversion into steam with a force equal to lifting it in height.										It is the absolute mechanical power forced into the water during its conversion into steam.	
One volume of water at 62° F., converted into steam occupies in											
One pound of steam in											
Temperature.		Elastic force					Feet standard power.	Total heat above.			
		lbs.		in				Fahrenheit 32°.	Centigrade 0°.		
Centigrade.	Fahrenheit.	Square inch.	Standard Base.	Inches of merc.	Atmospheres.	Cubic feet.				Volumes.	
											Deg.
							0	32	·089		·20542
10	50	·177	·40906	·3606	·012	1711·	106622·	43615	1097·10	609·5	
20	68	·336	·77659	·6847	·023	933·	58150·	45160	1102·68	612·6	
30	86	·610	1·4089	1·2421	·042	532·	33148·	46703	1108·26	615·7	
40	104	1·061	2·4521	2·1618	·072	316·	19676·	48247	1113·66	618·7	
50	122	1·778	4·1076	3·6213	·121	195·	12122·	49792	1119·06	621·7	
60	140	2·876	6·6446	5·8580	·196	124·	7726·	51336	1124·64	624·8	
70	158	4·505	10·409	9·1769	·306	82·	5080·	52880	1130·04	627·8	
80	176	6·854	15·837	13·962	·466	55·	3436·	54424	1135·62	630·9	
90	194	10·155	23·465	20·687	·691	38·	2385·	55968	1141·02	633·9	
100	212	14·689	33·940	29·922	1·000	27·19	1694·48	57510	1146·60	637·0	
110	230	20·784	48·023	42·338	1·415	19·73	1229·72	59056	1152·00	640·0	
120	248	28·822	66·597	58·713	1·962	14·60	909·95	60600	1157·58	643·1	
130	266	39·239	90·667	79·934	2·671	11·00	685·40	62144	1162·98	646·1	
140	284	52·530	121·363	106·995	3·576	8·420	524·77	63688	1168·56	649·2	
150	302	69·215	159·929	140·996	4·712	6·545	407·88	65232	1173·96	652·2	
160	320	89·902	207·730	183·138	6·120	5·158	321·45	66776	1179·51	655·3	
170	338	115·222	266·233	234·715	7·844	4·1176	256·62	68320	1184·94	658·3	
180	356	145·850	337·003	297·107	9·920	3·3266	207·31	69864	1190·52	661·4	
190	374	182·500	421·688	371·766	12·425	2·71713	169·35	71408	1195·92	664·4	
200	392	225·914	522·001	460·204	15·380	2·24249	139·754	72952	1201·50	667·5	
210	410	276·857	639·711	563·978	18·484	1·86859	116·452	74496	1206·90	670·5	
220	428	336·106	776·612	684·672	22·882	1·57110	97·9124	76040	1212·48	673·6	
230	446	404·447	934·523	823·887	27·535	1·33213	83·0198	77584	1217·88	676·6	
0	1	2	3	4	5	6	7	8	9	10	

NOTE.—Columns 3, 6, and 8, are new features in the table; the first (3) representing the pressure in pounds upon a base coincident with that of a column of water one foot high, which will weigh one pound. This base it is proposed to call the “*Standard Base*,” to be used instead of the “*square inch*” now used for that purpose. Multiplying the pounds of pressure per “*Standard Base*,” by the volumes into which the heat will expand the water in converting it into steam; (7) gives the next column, (8) representing the whole mechanical power of

the steam or the "*Standard Power*," which may be converted into horse power by being divided by 33,000.* Column 6 gives the number of cubic feet of steam which will weigh one pound. Columns 0, 5, and 10, are identical with M. Regnault's table at the end of his ninth Memoir, before referred to.

In applying this table to calculating the power of a steam engine working "differentially," according to the "*new method of applying and condensing steam*," I shall premise that any good oscillating engine will give out 82.5 per cent. of the power of the unbalanced steam.

In the "Memoir," vol. xxxi, p. 343, of this *Journal*, I have mentioned a back pressure in the "differential" method of applying the power of steam, as if it formed a necessary part of the system, that such back pressure should greatly exceed that of the atmosphere, which is not the fact, indeed it is just the reverse; when steam from a high pressure steam engine exhausts into the atmosphere, the back pressure on the piston must necessarily be greater than is due to the mere steam itself, because it is constantly surging to and fro at every stroke with the whole weight of the atmosphere, whereas, in my method, the back pressure is that of the steam in the condenser *only*, which is always leaving the piston, and the quantity of the condensing water being properly regulated, the pressure in the condenser may be kept at the pressure of the atmosphere to the greatest nicety, and thus prevent any of that surging *into* the exhaust pipe by the atmospheric air, and the *bellowing* of the steam to get it out again.

The one is a mere statical pressure, while the other is a dynamic force of the very worst kind for the steady working of the engine.

In comparing the new or "differential" method of applying and condensing steam, with the ordinary high pressure mode of exhausting into the atmosphere, (irrespective of the recuperative power of the former method,) we have to consider the amount of the back pressure of the latter over and above that of the atmosphere, to which (*viz*: the pressure of the atmosphere,) the differential method may be confined with a certain economy, to the extent of that difference, whatever it may be.

If this simple but incontrovertible fact is established, *viz*: that the "differential" method gets rid of the surging back pressure of the atmosphere as a dynamic force, and converts that pressure into a mere static one equal to that of the atmosphere only, then the consequences are inevitable, for, say that there is no loss merely, and is it not clear that the economy of bringing into operation the recuperative power of the "differential" method must inevitably cause its adoption? Firstly, because any increase of back pressure† which may be required, causes the feed-water to become so much hotter, as to fully compensate therefor, and the boiler is supplied with hot distilled water at no cost what-

*In calculating the effective power at 75 per cent. of the total power in the unbalanced steam, this divisor becomes 44,000 ($= 33,000 \div .75$); at 82.5 per cent., it is 40,000 ($= 33,000 \div .825$.)

†The back pressure is only necessary when distilled water is required, to obtain which, by any other means, involves the necessity of another boiler, to all intents and purposes as objectionable as those which it is the object of the surface condenser to remove, only, instead of having four boiler to blow off, but one is required, and hence, to that extent, there is a saving of engineer, but none of fuel, and none of boiler either, where copper tubes are used for the condenser while the boiler is of iron. See the February number of this *Journal*, vol. xxv, page 94.

ever, by means of which, its evaporative power and durability* are increased to an enormous extent. This consideration alone should settle the matter, for the known inefficiency of the air pump surface condensing steam engine, makes it entirely unnecessary to establish any comparison with it, but we may do so by way of making an example of the culprit.

Rule 1, for the "differential" method.

To ascertain the weight of steam required per minute for a steam engine of a given power, multiply the "*Standard Power*," (*i. e.*, the whole power in one pound of working steam in the cylinder,) by the pounds per "*Standard Base*" of unbalanced steam pressure, and divide the product by the pounds per "*Standard Base*" of working steam, and with it as a divisor, divide 40,000 times the horse power (H. P.,) required, and the product is the number of pounds of water per minute which must be converted into steam to furnish it.

To find the cubical contents of the cylinder in feet.

Rule 2. Multiply the number of pounds of steam as found by Rule 1, by the cubic feet in one pound of it by the table, and divide by the number of single strokes of the engine per minute, and the product is the capacity of the cylinder in cubic feet.

EXAMPLE I.—Required an engine of 3 H. P. to be worked with full steam of 160 lbs. per "Standard Base" of pressure of the working side, and 34 lbs. on the exhaust side of the piston = 126 lbs. of unbalanced steam, and making 400 single strokes per minute. Here we have 65,232 as the "*Standard Power*," corresponding with 160 lbs. per "Standard Base" of working steam, and 126 lbs. of unbalanced steam pressure.

Now, by Rule 1, $(65,232 \times 136) \div 160 = 51,370.2$, which represents the power of the unbalanced steam with one pound of working steam in pounds raised one foot.

Also, $(40,000 \times 3) = 120,000$. And, $(120,000 \div 51,370) = 2.336$ lbs. of water required to be converted into steam to supply 3 H. P. for one minute.

Again, by Rule 2, $(2.336 \times 6.545) \div 400 = .382228$ cubic feet, or 66.05 cubic inches in the cylinder.

Therefore, if the length of the stroke be taken at 6'', the area of the piston must be 11 ins. or 3.6 ins. diameter.

We may calculate, that 50 lbs. of feed water, pumped into the boiler of a steam engine at the full boiling point, may be evaporated from 10 feet of recipient heating surface in one hour, by 5 lbs. of coal burned on $\frac{1}{8}$ -th of a square foot of grate surface, and shall constitute one H. P., the unbalanced steam being equal to lifting 40,000 lbs., one foot high per minute. The steam shall be well dried and worked at full pressure throughout the stroke. The condensing water must be 200 lbs. or (4 times the weight of the feed water) of which 20 lbs.

*The durability of iron boilers is affected in a most extraordinary manner by cold water. Hot pure water appears to have but little or no effect upon it, except dissolving a little of the oxide, while cold water gives it the rheumatism, gets inside of it, and causes large flakes to peel off, whole lamina in fact. I have reason to believe that these remarks apply to some extent to sea water also, as they are well-known to apply to ordinary boiler water.

or $\cdot 10$ of the whole, or 4 times the weight of the fuel consumed, shall be evaporated from the hot-well for the following purposes, viz:—

	lbs.
Condensed, {	2 to make up for the waste from the boiler.
	3 for any purpose that it may be required for.
Uncondensed,	15 to improve the draft of the chimney.
	—
	20
	—

Here we have 50 lbs. of steam to condense, and 200 lbs. of water to do it with, but of the 50 lbs. of steam, 2 lbs. are allowed for waste, and 15 lbs. more is transferred to the 200 lbs. of condensing water, and goes off by the blast pipe in the shape of vapor, leaving but 33 lbs., ($= 50 - (2 + 15)$) of steam to be condensed by 185 lbs., $= (200 - 15)$ of water, for the 15 lbs. is equally lost, both as to the latent heat of the steam, and as condensing water. The 3 lbs. of vapor which is taken from the hot-well, and is to be condensed by the same stream of water which it is taken from, is practically the same as taking so much of the hot water itself.

And so we have $5 \cdot 606$ lbs. $= (185 \div 33)$ of the condensing water to condense 1 lb. of steam, and as the waste hot water which carries off the surplus heat runs away at 100° C., and the working steam at 150° C., has a total heat of $652 \cdot 2^{\circ}$, we have, $552 \cdot 2^{\circ}$ ($= 652 \cdot 2 - 100$) to run to waste, and $552 \cdot 2 \div 5 \cdot 606 = 98 \cdot 5^{\circ}$ gives the increase of temperature of the condensing water, which must therefore enter at $1 \cdot 5^{\circ}$ C., ($= 100 - 98 \cdot 5$) to effect the condensation if no allowance is made for radiation.

Now, let us analyze the whole of these productions and ascertain what we have got of available property in them, premising 1st. That we obtain one H. P. from the combustion of 5 lbs. of coal per hour, the engine working without expansion.

That is all we bargained for and the rest is surplusage—therefore:

2d. An abundance of distilled water to make up for the waste from the boiler, the importance of which is not fully appreciated, or no mere subterfuge would be tolerated for one moment, and that is a mere subterfuge which does not effect its whole object.

3d. Distilled water for the use of a ship, &c.

(NOTE.—Altogether 5 lbs. or $\frac{1}{8}$ -th gallon per hour for each H. P., is available for the above two purposes in ordinary cases.)

4th. 15 lbs. of vapor to improve the draft of the chimney, but if that is not needed, then it may be applied to the working of another steam engine, of the air pump condensing kind, and will give out 1·875 H. P.

(NOTE.—Taking the whole 20 lbs. of uncondensed vapor, the power obtainable from it is $\cdot 25$ H. P., so that in point of fact, we can obtain 1 H. P. from the combustion of 4 lbs. of coal per hour, the engine working without expansion. Taking this statement as including all the advantages obtainable from the steam, there is still something left in.)

5th. $22\frac{1}{2}$ gallons per hour per H. P. of boiling hot water.

As to the areas of the condensing surfaces, my experience thus far assigns to the

Main condenser,	3.00 feet suppl.
Heater “	0.75 “
Condensing surface,	3.75 feet per H. P.
Distilling condenser,	0.75
Condensing and distilling surfaces,	4.50 “

Finally. If the working steam is 100 lbs. per square inch of pressure above the atmosphere, and the back pressure is 6 lbs. above it, we shall have 1 H. P. from 43 lbs. of feed water evaporated by 4.3 lbs. of coal, or with an auxiliary air pump condensing engine to use up the whole of the low pressure steam, we shall obtain one horse power from the combustion of 3.44 lbs. of coal, and cutting off the steam at one-fourth of the length of its stroke will give one horse power from the combustion of 1.5 lbs., according to the usual mode of calculation, which, however, involves a great fallacy, for in this case, the advantage of cutting off at one-fourth of the length of the stroke will scarcely effect a saving of more than one-third of the fuel, and therefore 2.3 lbs. per hour per horse power is as low as can be calculated upon. The fallacious results usually arrived at in such calculations, arises from neglecting the space necessary for the clearance of the piston, as well as the steam in the passages, which even with such moderate expansion as allowed above is nearly half as much as the steam admitted.

I risk nothing in asserting that without expansion, the air-pump surface condensing engine will require upon the average not less than 90 lbs. of feed water per hour per horse power, and that, owing to the low temperature at which it must necessarily be pumped in, together with the ordinary scale upon the boilers, from having one-fourth of sea water in them, and the blowing off continually necessary, not more than 7.5 lbs. of such water can be evaporated with 1 lb. of coal, which shows that 12 lbs. of coal per hour is necessary on such a system, while 5 lbs. is sufficient on the new one.

The investigation which I have courted, will doubtless prove very tedious to any one who will take it up, but surely its importance should command some attention, if not as a mere theory even, at least as a successful result of several years' practical experience, both with salt and fresh water as the condensing medium.

In my next, I hope to be permitted, by the aid of a pictorial illustration, to show the *modus operandi* which I have adopted in carrying out the system, and also what becomes of the total heat in the exhaust steam, in such a manner as to defy all cavil, and assure the *unbelievers* that not only can steam be condensed with boiling hot water, but also that *more* distilled water “can be returned into the boiler than it evaporates.” And, furthermore, that both are done daily, and the method by which it is done is simple in the extreme, and open to the inspection of all.