sun-light. But they are not proof against vapors containing sulphuretted hydrogen; these, especially when aided by moisture, are not completely guarded against by red lead.—*Bulletin de la Societè d'Encouragement pour l'Industrie Nationale*, May, 1860.

For the Journal of the Franklin Institute.

Upon the Practical Relative Economy of using Steam with Different Measures of Expansion. By ALBAN C. STIMERS, Chief Engineer, U. S. Navy.

The most simple and obvious mode of using steam to obtain power in a steam engine, is to permit it to flow freely from the boiler into the cylinder during the entire stroke of the piston; and this was the plan adopted in the earliest engines.

The ingenious and philosophical mind of Watt, however, upon the announcement by Mariotte that the volume of the fixed gases, when maintained at a constant temperature and unaffected by the greater or less proximity of their molecules, was inversely as their pressure, or, conversely, that the pressure was inversely as their volume, soon made the application to steam; and, assuming this law and this application of it to be correct, it is easily shown that great gains in economical effect are produced by suppressing the flow of steam into the cylinder before the piston has completed its stroke, and permitting it to expand during the remainder. This was done by Watt, and apparatus for effecting this suppression at any desired point in the stroke, forms one of his many patents; but, notwithstanding the fact that both his mechanism and his patent covered the whole ground of the expansion question, that is, enabled him to cut off at any point in the stroke, his engines, which were generally paid for by a portion of the fuel he saved over that used by those displaced, were arranged, after a few trials, for suppressing the steam at about three-fourths the stroke of the piston.

Any one familiar with Watt's history must have observed how uniformly he put every important conception tending to improve the steam engine to the test of a practical experiment; and though we have no account of an especial set of experiments having been tried by him to test the exact value of the expansion principle, there is but little doubt that his very accurate practice would soon determine whether the practical result was equal to the theoretical prediction, and that, when he found it was not, he determined by a complete set of experiments the most favorable degree of expansion and its actual value in the practical steam engine. The fact that he published no account of such experiments is no proof against their having been made, as he had every incentive as a business man to permit his rivals to follow the natural proneness of mankind for settling all such questions by mathematical demonstration rather than by carefully-conducted experiments, which require time, money, ingenuity, patience, and a much greater knowledge of the physical laws, for drawing correct inferences from the experimental data than is needed in any cal-

culatation where the data is all assumed; having ascertained to his own satisfaction that all such calculations, based upon his own invention, the indicator diagram, would lead them to adopt a more unfavorable degree of expansion than had been decided upon for him by his experiments, thus causing them to produce engines inferior to his own.

The steam engine establishment of Boulton and Watt is still in existence, having descended from father to son during eighty-six years, and the general practice of the present firm with regard to this question is the same to-day that it was sixty years ago. It cannot be considered as at all strange that the practice of so successful and celebrated an establishment should be imitated as closely as possible by a large majority of steam engine builders as soon as the expiration of their patents destroyed their monopoly; and this we find to have been the case in fact, even in our own country. The swift and powerful steamers upon the Hudson, in their palmy days, only differed materially from the practice of the above establishment by using a higher pressure, the steam being cut off almost uniformly at five-eighths of the stroke of piston. The same degree of expansion is also used in the engines of the steamers upon the Mississippi and its tributaries.

It is true that in river boats the greater dimensions and consequent weight of the larger engines required to use the steam very expansively may be a much greater objection than it is in most of the applications of steam power, and that, consequently, the fact of the lesser degree of expansion being used in them, is not in itself a proof of its greater economy; but, an examination of the subject will prove that the advantages of obtaining great power with small engines are not, in either of these instances, at the expense of economy in fuel.

Until quite recently, it was the exception, and not the rule, to find new engines cutting off at less than half the stroke of the piston, and even now it is doubtful if a majority of all the steam engines in existence are arranged for expanding the steam as much as twice. The impression, therefore, which appears to be quite general, that any experiments which prove that the law of Mariotte cannot be applied to the practical steam engine to determine its economy when the steam is being expanded several times, are contrary to the experience of the whole engineering profession ever since its birth, is a very mistaken one. The indefatigable persistence, however, of the patentees of adjustable cut-offs, who wish to "sell rights," together with the remarkable coincidence which exists between the indicator diagram as formed by an engine when expanding the steam several times, and that called for by the simple application of the law of Mariotte, have exerted of late years a powerful influence in causing engines to be built with the design of permitting the steam to expand a great number of times.

The apparent success of some of the extreme applications lately made of this principle, was rapidly causing a great revolution in the practice of the profession; so much so, that when Chief Engineer Isherwood, of the U. S. Navy, had the practical sagacity to perceive that the actual economy of any engine in which the steam was greatly expanded was not nearly equal to what it should have attained if there

had been no drawbacks to the application of the theory, and proceeded to publish a book, giving, among other things, an account of experiments he had made to test the question, and explaining their rationale, it was met with severe criticism from nearly every quarter. He was looked upon as a man who was endeavoring to thrust the steam engine back into the darkness from which it was just emerging. By no one was this view taken more strongly than by the present writer, who shared the general feeling that the experiments detailed in the book were not of a character to justify its author in what appeared to be such radical conclusions, overthrowing, at one fell stroke, all our pre-conceived ideas respecting the power of the indicator diagram to determine the amount of steam which had entered the cylinder.

After the issue of the above book, and during the year 1860, Mr. Isherwood was almost constantly engaged, under orders from the Navy Department, in experiments showing the relative economy of using steam with different manners of expansion. Such of the results of these as became known to the public, were so different from what would have been predicted by what had become to be regarded as established theories, that a memorial was addressed by a large number of steam engine manufacturers and others, to the Secretary of the Navy, praying him to cause a complete set of experiments to be tried with the engines of some of our national vessels by a Board of Naval Engineers. This was granted, and a Board, consisting of Chief Engineers B. F. Isherwood, Theodore Zeller, Robert H. Long, and Alban C. Stimers, was ordered to convene on board the U. S. Steamer *Michigan*, at Erie, Penna., on the 19th of November, 1860.

When the writer joined this Board, he had very little doubt about the result. He had been taught in his engineering education to consider the indicator diagram as an exponent of the economy of the engine which formed it, whatever the degree of expansion, and although he had experienced some unaccountable deficiencies in the evaporative powers of boilers attached to engines using large measures of expansion, he had never suspected that the difficulty lay in the engines and not in the boilers or the coal. And as an experiment was not in itself an argument upon this side or that of any question, but the true determination of the real facts; he believed that these would prove to be, that decided benefits were obtained by expanding the steam as many as three times at least in that kind of engines, namely: unjacketed cylinders using saturated steam, and without regard to the opinions or expectations of the others, he satisfied himself thoroughly of the propriety of every preparation made before commencing the experiments and watched narrowly their whole conduct afterward; being determined that whatever they would be to people in general, to him they should prove the *experimentum crucis*, as far as these engines were capable of determining the question. This they have done, and they prove to his entire satisfaction that it is utterly futile to attempt to realize any benefit by expanding the steam beyond one and a half times, under the conditions above described.

The following description of the machinery; of the manner of making

the experiments; of obtaining the data; and of calculating the results; together with the reasons for the same, and the reductions formed, may be considered as condensed from the Report of the Board, which being very minute and circumstantial, is too long for a magazine article.

The selection by the Navy Department of the machinery of the U. S. Steamer *Michigan* for making these experiments was determined by its appropriateness and convenience; the engines being of the medium size used for marine purposes and the vessel out of commission; the former had just been thoroughly repaired and furnished with new boilers.

Description of the Boilers.—The boilers are two in number, placed side by side, six inches apart, with one smoke-pipe in common at the front end. They are of the type known as *Martin's patent*, but with proportions somewhat different from those adopted by the patentee; these were designed by Samuel Archbold, Esq., the Engineer in Chief of the Navy, for the purpose of burning to the greatest advantage the highly gaseous coal found on the borders of Lake Erie, in Pennsylvania and Ohio, and universally used by the steamers on the lakes, to the waters of which the cruising of the *Michigan* is confined.

These peculiarities are:

1. The greater length of the tube-box, which is about one and a half times more than the patentee employs.

2. The greater width in the clear between the tubes crosswise the furnaces, which is about two and a half times that which the patentee employs.

3. The greater calorimeter for draft between the tubes, which is double the patentee's proportion, while the area of the smoke-pipe, instead of being equal to this calorimeter, is only about half of it.

4. The employment of a much larger combustion chamber between the furnace and the tubes than the patentee adopts.

5. The furnishing a copious supply of air, not only to the furnaces through perforations in the doors, but to the bottom of the combustion chambers, through perforations in the lower part of the bridge-wall.

The whole of the boilers and steam chimney are well covered with felt. The heating surface given below is calculated for every part with which the heated gases come in contact—top, sides, and bottom—and for the external circumference of the tubes.

The following are their principal dimensions:—

Length of each boiler at the furnaces (fore and aft the vessel),	15 feet 8 inches.
“ “ at top of flues,	16 “ 8 “
Breadth “	9 “ 2 “
Height “ exclusive of steam chimney,	9 “ 2 “
Number of furnaces in each boiler,	3.
Width of each furnace,	2 “ 6 “
Length of grate bars,	6 “
Height from bottom of ash-pit to top of grate bars at front of furnace,	1 “ 9 “
Height of crown of furnace from bottom of ash-pit at front of furnace,	4 “
“ “ from top of bridge-wall,	1 “ 3 “
External diameter of tubes,	2 “
Length of tubes between tube sheets,	1 “ 8 “
Whole number of tubes,	1504.
Total area of grate surface, in both boilers,	90 sq. ft.
“ of water-heating surface, in both boilers,	2689.59 “
“ of steam-heating “ “	84.71 “

Diameter of the smoke-pipe,	.	.	.	4 feet 3 inches.
Height	"	above grate surface,	.	45 "
Steam space in the two boilers and steam chimney, 530 cub. ft.				
Weight of water in the two boilers, at a temperature of 262° Fahr., measured to the height carried during the experiments, 46,450 lbs.				

PROPORTIONS.—Ratio of water heating to grate surface,				29 884 to 1.
"	steam	"	"	0.941 to 1.
"	grate surface to least cross area betw'n tubes,			3.212 to 1.
"	"	to area of smoke-pipe,		6.344 to 1.

Description of the Engines.—The engines are two in number, condensing, direct-acting, and inclined from the keel at an angle of 23 degrees: they are placed side by side in the vessel with a passage-way $4\frac{1}{2}$ feet wide between them. They occupy in the vessel a space 15 feet wide, including the above passage between them, by 35 feet long, and a height from top of keelsons to top of main pillow blocks of $13\frac{1}{2}$ ft.

The air-pump is inclined like the cylinder, the axis of both being parallel. It is a single-acting piston-pump, with a solid piston, and one end open to the atmosphere.

The condenser is the common jet kind, situated immediately beneath the cylinder.

The cylinder steam and exhaust valves are the double poppet kind habitually used in the United States for marine paddle-wheel engines. The upper and lower valve chests are connected by a steam and an exhaust pipe, the axes of which are parallel with the axis of the cylinder.

The cylinder steam valves are made to act as expansion valves by means of a valve-gear known as *Sickle's cut-off*. As applied to these engines, the valve was tripped by its own movement when the spring came in contact with the inclined face of a fixed cam, which could be adjusted by means of a screw. By this arrangement, the point of cutting-off could be graduated from nearly the commencement up to $\frac{3}{4}$ of the stroke of the piston, and from $\frac{1}{10}$ up to $\frac{1}{2}$ of the stroke, at which point the valve seated by the eccentric movement without tripping. Between $\frac{3}{4}$ and $\frac{1}{10}$ of the stroke it was impossible to suppress the admission of the steam.

Each end of the cylinder is provided with a relief valve for the discharge of the waste water.

The steam pipe between the boilers and cross pipe to the two engines, in which is placed a throttle valve to each engine, is $25\frac{1}{2}$ feet long by $17\frac{3}{4}$ inches diameter. The cross pipe is $4\frac{3}{4}$ feet long by $15\frac{1}{4}$ inches diameter, and the steam side pipe of each cylinder is $7\frac{1}{2}$ feet long by $12\frac{1}{4}$ inches diameter, giving a total interior surface when one engine is used, for the radiation of the heat, of 156.5 square feet, and as there is a slight inclination towards the cylinder throughout the whole length of the steam pipes, any water condensed in them is passed through the cylinder.

The steam pipes, side pipes, and cylinders are protected with a thick coat of felt covered with wooden lagging. The heads of the cylinders, the valve chests, and cylinder nozzles have no covering.

The lower head of each cylinder is double, the upper one is single.

Diameter of cylinder,	.	.	.	36 inches.
Stroke of piston,	.	.	.	8 feet.
Diameter of piston rod,	.	.	.	3 $\frac{1}{4}$ "
Mean area of piston, exclusive of rod,	.	.	1012.278 sq. ins.	
Space displacement of piston per stroke, excl. of rod,	.	.	56 514 cub ft.	
Steam space comprised in the clearance and nozzle,	.	.	3.280 "	
Net area of opening through steam valve, exclusive of stem, &c.,	.	.	114.96 sq. ins.	
Net area of opening through exhaust valve, exclusive of stem, &c.,	.	.	108.38 "	
Diameter of air-pump,	.	.	.	29 "
Stroke of air-pump piston,	.	.	.	31 $\frac{1}{2}$ "
Space displacement of air-pump piston per stroke,	.	.	12 cub. ft.	
Diameter of feed pump and of bilge pump,	.	.	.	5 7-16 "
Stroke of piston of "	.	.	.	31 $\frac{1}{2}$ "
Capacity of one condenser,	.	.	20 "	
" hot-well,	.	.	27 "	
Length of connecting rod,	.	.	16 "	5 "

PADDLE WHEELS.—The arms, rims, and braces of the paddle-wheels, are of iron; the paddles are of wood, 1 $\frac{1}{2}$ inches thick, chamfered at the edges. Each paddle is divided in its breadth.

Diameter to outside of paddles,	.	.	.	21 feet 6 inches.
Number of paddles in each wheel,	.	.	16.	
Breadth of outer fraction of paddle,	.	.	.	1 " 2 "
" inner "	.	.	.	1 " 5 "
Length of paddles,	.	.	.	8 "
Immersion of the lower edge of paddle,	.	.	.	2 " 8 "

NOTE.—The above is the normal surface and dip, but during the experiments these greatly varied, different numbers of buckets being removed for different experiments, and sometimes several getting broken by the ice during the same experiment. The vessel, too, was so near the ground, that, as the water ebbed and flowed by the influence of the winds, it was sometimes afloat and sometimes aground, varying the dip according to the extent of the fall of the water: the experiments being made with the vessel lashed to the wharf in the harbor of Erie.

Manner of Making the Experiments.—The experiments were made with the starboard engine alone and with both boilers. The following are the quantities and the mode of obtaining them, which were ascertained by direct measurement or weights.

The number of double strokes made by the engine piston were registered by one of Rogers' engine counters.

The number of pounds of coal consumed, of ashes, clinker, and soot, forming the refuse from the coal, were accurately weighed on one of Fairbanks' platform scales, quite new, and tested previous to its being used.

The steam pressure in the boilers was shown by one of Allen's spring gauges and by a mercurial syphon gauge, the two coinciding.

The vacuum in the condenser was denoted by one of Allen's spring vacuum gauges.

The steam pressure in the cylinder throughout the stroke of the piston, was obtained by taking indicator diagrams hourly from each end of the cylinder with excellent instruments of the New York Novelty Iron Works manufacture. Those shown in the plate are fair samples of those taken during each experiment.

The pressure of the atmosphere was denoted by an aneroid barometer, which hung in the centre of the engine room. This was used to determine in each case the back pressure in the cylinder.

The temperatures of the injection water, of the feed water in the tank, of the external atmosphere, and of the engine room, were measured by thermometers of the ordinary description; that of the hot-well was shown by a large fixed thermometer having its bulb constantly immersed in the water in the interior of the well.

The feed water, before being pumped into the boilers, was first pumped into a wooden tank lined throughout with zinc, and as the hose through which the water was each time pumped into it and the pipe through which it was withdrawn by the feed pump passed over the top, there were no joints to cause leakage. In addition to this precaution against error in measuring the amount of water evaporated, the tank was blocked up from the engine room floor 3 inches; so that if any leakage should occur from any cause, it would be immediately discovered. The internal dimensions of the tank were as follows:—length $11\frac{1}{2}$ feet, breadth $1\frac{3}{4}$ feet, height $3\frac{7}{8}$ feet. It was filled each time to a convenient mark which corresponded accurately with a capacity of 70 cubic feet. Great care was taken in making the connexions between this tank and the feed pump to shut off absolutely every other source from which the pump could be supplied, and to close all avenues of egress from the pump except those which conducted the water to the boilers.

The boilers were fitted with the usual gauge cocks and with glass water gauges; these latter enabled the height of the water within to be noted with great exactness by tying a piece of small twine around the glass tube at the height of the water. When an experiment was commenced, the piece of twine was made to correspond exactly with the water level, which was brought again to the same level at the end of the experiment.

The water supplied to the boilers being fresh and almost absolutely pure, no blowing off was required; all the water, therefore, which was measured in the tank was available for making steam. Great care was taken before commencing the experiments to have all valves and cocks through which water or steam could leak from the boilers made absolutely tight, and afterwards a regular system of inspection was adopted that any new leak might be at once discovered. With regard to the boilers themselves, they were quite new, and, as far as could be ascertained by the most rigid scrutiny, were absolutely tight.

Each experiment lasted 72 consecutive hours, during which the engine was neither stopped, slowed down, nor in any way changed in condition. In commencing an experiment, the engine was operated for several hours to adjust it to the normal conditions required to be uniformly maintained during that experiment and to bring the fires to steady action. When all was ready, average fires and the proper steam pressure being in the boilers, the time and number of the engine counter were noted, and the experiment began. From this time up to the end of the 72 hours all the quantities were weighed or measured and

noted hourly in a regular *log*, ruled with appropriate columns. As the end of the experiment approached, care was taken to bring the fires to the same state of cleanliness and to the same thickness which they had at the beginning. The means or totals then, as the case required, of the quantities entered in the *log* furnished, with the exception of the facts derived from the indicator diagrams, the data for that experiment.

Each of the 144 diagrams taken during one experiment was carefully analyzed and its results arranged in tabular form, so that the mean of the whole number was conveniently obtained by getting the mean of the whole number of quantities in each column of the table. The quantities thus found were,

The pressure in the cylinder at the commencement of the stroke,

The pressure in the cylinder at the point of cutting off,

The final pressure at the end of the stroke of the piston,

The mean back pressure,

The mean gross effective pressure, and

The fraction of the stroke completed when the steam was cut off.

At the close of the experiments, the pressure on the piston required to operate the engine *per se* was obtained by removing all the paddles from the wheels and running the engines, taking indicator diagrams to get the pressure. Of course the arms of the paddle wheels acted, to a certain extent, propulsively upon the water, and to eliminate this quantity the engine was run at various speeds, ranging from 8 to 22 double strokes per minute, and taking several sets of diagrams for each rate of speed to get a reliable mean. Now, the resistance to the passage of the paddle wheel arms through the water was variable and required an increased piston pressure with each increase in the speed, while the piston pressure required to overcome the friction of the engine would be constant for all speeds; by eliminating, then, the variable quantity, the constant quantity remaining would be the correct pressure required solely for overcoming the friction. This was found to be 2.1 pounds per square inch.

In reporting the experiments, the Board make out two tables containing all the data and results observed and calculated; embracing only those trials in which all the conditions from beginning to end were such as could satisfy the most hypercritical, and moreover they are those which give the highest results to the greater measures of expansion. The first table contains the exact experimental determinations under the conditions noted, and is made out in great detail. The second contains the results detailed in the first, but calculated only for weight of steam used in rapport of power developed, and corrected for equality of back pressure against the piston, which equality did not obtain in the experiments, but which it is necessary to adopt in order to show the *true* relative economy of the different measures of expansion employed; for whatever absence of back pressure can be obtained in one case can in any other. This second table of the Report contains, therefore, all that is really essential to a correct understanding of the results obtained by the experiments, and is the only one of the two given in this paper.

TABLE: Containing the Results of the Experiments, calculated for Equality of Back-pressure against the Piston, and showing the True Relative Economy of using Steam with Different Measures of Expansion.

FRACTION OF STROKE COMPLETED WHEN STEAM WAS CUT OFF.										
		$\frac{1}{1}$	$\frac{1}{2}$	$\frac{7}{10}$	$\frac{4}{9}$	$\frac{3}{10}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$
1	In pounds per square inch above zero at beginning of stroke of piston,	34.8	33.3	34.5	34.4	34.3	34.3	34.2	34.7	
2	" " at point of cutting off the steam,	32.2	31.4	33.0	33.4	33.3	33.3	33.2	33.0	
3	" " at end of stroke of piston,	29.3	22.2	15.7	11.0	9.7	7.8	5.9		
4	" " against piston during the stroke,	27	27	27	27	27	27	27	27	
5	Mean gross effective pressure in pounds per square inch on piston during its stroke,	31.3	28.4	24.4	20.2	17.4	13.7	9.8		
6	Pressure in pounds per square inch on piston, required to work the engine, <i>per se</i> ,	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	
7	Mean net effective pressure in pounds per square inch of piston,	29.2	26.3	22.3	18.1	15.3	11.6	7.7		
8	Per centum which the mean net effective pressure is of the total pressure,	85.9	84.6	82.3	79.0	76.1	70.7	61.6		
9	Gross effective horses power developed by the engine,	316.604	216.905	206.966	135.727	118.434	75.095	67.821		
10	Total horses power developed by the engine,	343.915	237.627	229.868	153.869	136.812	89.895	86.508		
11	Net horses power usefully applied,	295.362	200.867	189.153	121.617	104.140	63.584	53.288		
12	Pounds of steam consumed per hour per gross effective horses power,	38.029	33.817	32.671	34.681	34.472	36.769	41.382		
13	" " total	35.008	30.881	29.416	30.592	29.841	30.715	32.044		
14	" " net	40.763	36.561	35.748	38.705	39.202	43.425	52.669		
15	Speed of the piston in feet per minute,	329.744	248.967	276.512	219.040	221.888	178.688	225.600		
16	Comparative bulks of steam withdrawn from the boilers in equal times,	1.000	0.609	0.561	0.391	0.339	0.229	0.233		
17	Mean total pressure on piston in pounds per square inch, by Mariotte's law,	34.5	31.3	27.6	23.2	21.2	17.2	12.6		
18	" " by experiment,	34.0	31.1	27.1	22.9	20.1	16.4	12.5		
19	Comparative economic result, by Mariotte's law, for the total horses power,	1.000	0.835	0.660	0.568	0.532	0.475	0.422		
20	" " by experiment, for the gross effective horses power,	1.000	0.889	0.855	0.912	0.906	0.967	1.088		
21	" " total	1.000	0.882	0.840	0.874	0.882	0.877	0.915		
22	" " net	1.000	0.896	0.877	0.949	0.962	1.065	1.292		
23	Comparative capacity of cylinder required to develop equal net horses power,	1.000	1.110	1.309	1.613	1.909	2.517	3.792		
24	Weight of steam condensed in the cylinder due to the heat annihilated in producing the total power, according to Joule's equivalent; expressed in per centum of the feed-water,	7.80	8.74	9.04	8.59	8.77	8.45	7.94		
25	Discrepancy between the tank and indicator measurements of the feed-water; expressed in per centum of the latter,	2.91	6.60	18.14	33.07	30.84	33.66	37.16		

EXPLANATION OF THE TABLE.

For facility of reference, the quantities are arranged in groups, and the lines containing them numbered.

Line 4 contains the corrected back-pressure above zero, in pounds per square inch against the piston during its stroke. The quantity 2.7 pounds was adopted for this purpose, because it is the least given during the experiments, and as with equal initial cylinder pressures the results are more unfavorably affected by back-pressure as the steam is used more expansively, it was deemed proper to accept the least practicable. The average with steam engines under the conditions of ordinary practice, is about 4 pounds, which, if adopted, would make the economic results much less favorable to the greater measures of expansion.

Lines 5 and 7 have been corrected from the experimental determinations to what they would have been, had the back-pressure been uniformly 2.7 pounds.

Lines 9, 10, and 11, contain, respectively, the gross effective, the total, and the net indicated horses power developed by the engine when using the pressures given on lines 5, 18, and 7, and having a speed of piston corresponding to those given on line 15.

Lines 12, 13, and 14, contain, respectively, the number of pounds of feed-water consumed per hour to produce the gross effective, total, and net indicated horses power, as given before.

Line 17 contains the mean total pressure, or pressure above zero on the piston, in pounds per square inch, that should exist according to the law of Mariotte. It is calculated for the experimental conditions of the steam comprised in the clearance and cylinder nozzles, and of the cylinder pressures at the beginning of the stroke, and at the point of cutting off the steam (lines 1 and 2). By comparing the quantities on this line with those on line 18, which are the mean total pressures on the piston as shown by the indicator, a remarkable coincidence will be found. That it is only a coincidence, is evident when it is remembered that, in order that the one should be a consequence of the other, it would be necessary that neither condensation, from any cause, nor re-evaporation should have occurred in the cylinder, from the point of cutting off to the end of the stroke of the piston, and that the steam should have expanded precisely in the inverse ratio of the spaces occupied.

Line 19, exhibits, comparatively, the economic result that should have been obtained with the different measures of expansion used for the steam, according to Mariotte's law. The calculation is made for the total horses power developed, and for the conditions which were obtained in the experiments, with the exception, only, that the steam is supposed to follow this law, agreeably to the general belief among engineers. In order to ascertain how nearly the steam comes up to the assumed law, in the ordinary steam engine cylinder, it is only necessary to compare the quantities in this line with those on line 21, which show the comparative cost of obtaining a given total horse

power, with the different measures of expansion employed, as determined by the experiments.

It is plain from these figures that the law of Mariotte cannot be employed to determine, even approximately, the economy of any engine which is using the steam expansively to any extent; although, in calculations for simply determining the power, it appears to be as safe a reliance as has all along been supposed by the most firm believer in its applicability to steam when expanding in an engine cylinder. Indeed, engineers were in the habit of making this comparison, which is readily done from the indicator diagram itself when the clearance is known, and it was one of the evidences which satisfied the mind that there was no danger of making any material error in taking the diagram as an exponent of the economy of the engine. Any difficulty in getting the expected economy from large measures of expansion, always appeared to be that the boilers failed to evaporate the proper amount of water per pound of coal, and either they or the coal itself were condemned as not being equal to expectation: the guilty engine not being even suspected.

Line 22 gives, comparatively, the cost in fuel of a given useful effect produced by the engine, and determines, *per se*, the practical relative economy with regard to fuel alone, of using steam with the different measures of expansion employed. To determine, however, the propriety of designing an engine with the view of using the most economical measure of expansion employed in the experiments, it is necessary to consider, in connexion with this, the quantities on line 23, which show the comparative capacity of cylinder required to produce, *cæteris parabus*, a given power with the net effective pressures given on line 7. The weight, space occupied, and first cost of steam engines proper, decrease in a more rapid ratio than the capacities of their cylinders. It is, therefore, perfectly safe to assume that these quantities vary with those on line 23, and, when this is done, an estimate, however roughly approximative, points inevitably to the fraction of $\frac{1}{10}$ as being the most economical one for cutting off the steam.

Lines 24 and 25 exhibit the difference, due to all causes, between the weight of feed-water pumped into the boilers, according to the tank, and the weight of steam discharged from the cylinder into the condenser at the end of the stroke of the piston, per indicator, expressed in per centums of the feed-water. Line 24 shows that part of it which is condensed in consequence of the heat annihilated in the cylinder to produce the total power developed by the engine, according to Joule's equivalent of one pound of water raised one degree of temperature on Fahrenheit's scale for every 772 foot-pounds developed by the engine; which would make the thermal equivalent of

one indicated horse power, $\left(\frac{33,000}{772} =\right)$ 42·7461 pounds of water raised one degree Fahrenheit.

To make the calculation, let k = the number of *total* indicated horses power (line 10), developed by the engine; e = the total heat

of steam of the pressure at the end of the stroke of the piston (line 3), in degrees Fahr. according to Regnault; g = the temperature in degrees Fahr. of the same steam; and t = the time in minutes ($60 \times 72 = 4320$) during which the power, k , acted: then, $\frac{k \times 42.7461 \times t}{e - g}$

= the number of pounds of steam condensed from this cause during one experiment. The per centum which this total quantity is of the total quantity pumped into the boilers during the experiment, is then obtained for the quantities on line 24.

The causes of the remaining differences, given on line 25, may be numerous. If the boilers lose water by leakage, by priming, or by passing it over to the cylinder in the vesicular state, the quantity thus lost will be included. If the cylinder valves or the piston leak steam to the condenser, the quantity thus leaked will be included. If the steam be condensed in the steam-pipe, valve-chests, or cylinder, from any causes other than the production of the power, and if a portion of the water formed by this condensation be re-evaporated in the cylinder, then the difference of the weights condensed and re-evaporated will be included. By taking these quantities into consideration when comparing the economic results for total powers that should have been obtained according to the law of Mariotte (line 19) with those obtained by experiment (line 21), a very clear idea will be had of the great antagonistic cause that neutralizes and reverses the economy promised by the purely abstract conditions on which that law is founded.

DISCUSSION OF THE RESULTS.

The Initial Pressure.—In examining the preceding table, it will be observed that particular care was taken to maintain the initial cylinder pressure (line 1) the same in all the experiments as nearly as practicable. That this is a proper condition for the purpose of the experiments, will be obvious when it is considered that degree of pressure is purely a question of boiler, and not at all one of engine. It is just as feasible to carry a high pressure and cut off the steam at $\frac{7}{10}$ of the stroke of the piston, as it is when cutting off at $\frac{1}{10}$, if the cylinder of the engine be of the proper dimensions. In considering subjects of this nature, it is very important that they be properly analyzed, so that but one element is determined at a time. To give the larger measures of expansion the benefit which is due to a higher pressure of steam, is not the way to ascertain how much benefit there is to be derived from expansion *per se*,—the object of these experiments.

It is, however, very useful to know the relative economy of developing, in the same engine, the same power with different measures of expansion; the greater measures having a correspondingly higher initial pressure in the cylinder, so that equal mean net pressures are exerted upon the piston during its stroke. The principal gain in using a higher pressure of steam in the cylinder of a steam engine, is to reduce the per centum of loss by the sum of the back and friction pressures, but when comparing results from *total* pressures alone, this element could not of course enter into consideration. Now, if we have

with the different measures of expansion, different initial pressures, such as the *net* pressures are equal, we shall have also equal *total* pressures; as the back and friction pressures are constant quantities; and as, leaving out of consideration the slight increase of dynamic effect due to increased temperature in the higher pressures, any numbers which express the comparative economy of different measures of expansion in rapport of *total* power are independent of the initial pressure of the steam; they express also the comparative economy of the same measures of expansion in rapport of *net* power, when equal mean pressures are maintained during the different degrees of expansion. The numbers, therefore, in line 21 express the comparative economy of the different measures of expansion employed in the experiments when the same engine is used to exert the same power, but with increased initial pressure with each increase in the degree of expansion.

Modification of Power.—The economic efficiency of any given engine is greatest when using its maximum mean total pressure; because then it has both the advantages of the greater dilatation due to the higher temperatures and the greater proportion of *net* to *total* pressure. In most applications of the steam engine, however, it is necessary to sometimes use considerably less than the maximum power, and it becomes a question of considerable importance to know how to do it with the least loss of economical efficiency. There are three modes in common use for reducing the power of the engine below the maximum, as follows: 1st, By reducing the boiler pressure; 2d, By partially closing the throttle valve and maintaining the same boiler pressure; and, 3d, By suppressing the steam at an earlier portion of the stroke by means of an adjustable cut-off and maintaining the same boiler pressure.

The impression obtains very generally among engineers, that the second of these plans is a decided improvement upon the first, and that the third is a still more decided improvement upon the second.

The first method reduces the mean pressure without any change whatever in the degree of expansion. The third does it entirely by increasing the measure of expansion, and the second may be said to be a compromise between the other two methods. Now, it happens, fortunately, that the foregoing table furnishes all the necessary experimental quantities required for determining the relative economy of the first and third methods, and as the second falls between these two, it will hereafter be seen that it is not important to know its exact economy.

The first three and the fifth lines in the following table are taken from the foregoing general table. Line 1 represents the total pressures, line 2 the net pressures, and line 3 the per centum which the latter are of the former. These last quantities represent the relative net power that would be obtained per unit of weight of fuel when using the steam with the same measure of expansion, but with the different net pressures on line 2; and by dividing unity by each of them we obtain a new set of quantities that show the relative cost in fuel of the unit of net power. Then, calling the one unity which falls into the column headed $\frac{1}{10}$ (that being the point recommended for permanently cutting off the steam), we obtain the proportional quantities on line 4,

which represent the comparative cost of the power when maintaining the same degree of expansion, and changing the net pressures to those found in the other columns on line 2 by varying the boiler pressure.

The quantities on line 5 are those on line 22 of the general table, but arranged for unity in the column headed $\frac{7}{10}$, instead of that headed $\frac{1}{2}$, and show the comparative economy of changing the net pressures to those found in the other columns on line 2 by retaining the same initial pressure and varying the measure of expansion.

The differences between the respective quantities on these two lines are given on line 6, and represent the per centum of loss or gain experienced by avoiding a complicated piece of mechanism, and reducing the power by merely reducing the boiler pressure without the assistance of any mechanism whatever.

	FRACTION OF THE STROKE COMPLETED WHEN THE STEAM WAS CUT OFF.						
	$\frac{1}{2}$	$\frac{7}{10}$	$\frac{9}{10}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$
1	34.0	31.1	27.1	22.9	20.1	16.4	12.5
2	29.2	26.3	22.3	18.1	15.3	11.6	7.7
3	85.9	84.6	82.3	79.0	76.1	70.7	61.6
4	0.985	1.000	1.027	1.061	1.111	1.196	1.373
5	1.116	1.000	0.978	1.059	1.073	1.188	1.442
6	Gain, 13.1.		Loss, 4.9.	Loss, 0.2.	Loss, 3.8.	Loss, 0.8.	Gain, 6.9.

It will readily be perceived that for greater measures of expansion than that obtained by cutting off at $\frac{7}{10}$, there is really no practical difference in the economy of the two methods; and as the use of the throttle valve, the most convenient of the three plans, comes between the other two in its economic efficiency, it may be considered as neither more nor less economical than the adjustable cut-off, but has the decided advantage of being extremely simple in its construction and convenient to manage.

Loss by clearance in the Cylinder.—There is a loss of useful effect in every steam engine by being required to fill the *clearance* at every stroke; and the per centum of this loss is different with different measures of expansion. An examination of the subject will tend to explain in part why we do not obtain in practice the whole benefit promised by the theory of expansion.

When the engine is working full stroke, the per centum of loss is exactly equal to that which the amount of space comprised in the clearance, is of the whole space filled with steam per stroke. In the case of using steam expansively, however, this ratio is modified; a part of the steam in the clearance producing a dynamic effect during expansion, and on the other hand, the space comprised in the clearance being constant, the shorter the steam is cut off the greater becomes the ratio which this space bears to that filled with steam before the valve closes.

To ascertain the per centum of loss experienced from this cause, it is necessary to imagine an engine running without any clearance what-

ever, and to compare its economy with that experimented upon. The results of such a comparison are given in the following table. Line 1 contains the effective pressures in pounds per square inch on the piston according to the law of Mariotte under the experimental conditions. Line 2 contains what would have been the net effective pressures according to the same law had there been no clearance and had the same amount of steam been admitted to the cylinder per stroke; in which case the measures of expansion would have been correspondingly lessened. Line 3 contains the difference between the quantities on lines 1 and 2. Line 4 contains the per centums which the quantities on line 3 are of those on line 2.

	FRACTION OF THE STROKE COMPLETED WHEN THE STEAM WAS CUT OFF.						
	$\frac{1}{12}$	$\frac{7}{10}$	$\frac{4}{9}$	$\frac{3}{10}$	$\frac{1}{4}$	$\frac{1}{6}$	$\frac{4}{45}$
1	29.7	26.5	22.8	18.3	16.4	12.4	7.8
2	29.9	26.9	23.9	19.8	17.8	14.1	9.1
3	0.2	0.4	1.1	1.5	1.4	1.7	1.3
4	0.07	1.49	4.60	7.58	7.86	12.06	14.29

An inspection of line 4 of the above table will show how rapidly the loss due to clearance increases with the measure of expansion.

Condensation in the Cylinder.—A comparison of the quantities on line 25 of the general table, will give at once a correct impression of the principal cause why we do not obtain in practice any approach to the gain promised by the theory when using steam expansively. The discrepancy between the indicator and tank measurements of the water evaporated it will be observed, is very small, only 2.91 per centum, when cutting off at $\frac{1}{12}$, but rapidly increases to the enormous amount of 33.07 per centum, when cutting off at $\frac{3}{10}$, and this is considered as using expansion very moderately. In the 2.91 per centum is included every kind of leakage, and the condensation due to radiation of heat from the steam-pipe, steam-chests, and cylinder, and as the loss from these causes was necessarily constant during all the experiments, it was evidently too small to be considered. Condensation within the cylinder due to the varying temperatures and pressures occurring therein at every stroke of the piston, is the only explanation which can be given; and the only accepted law of physics which could cause the condensation, requires that the surfaces with which the inflowing steam comes in contact, should be cooler than itself; the condensation taking place upon those surfaces.

The surfaces of the cylinder are cooled down below the temperature of the steam of initial pressure, partly by being in contact during a portion of each double stroke of the piston with vapor of less temperature than that to which they have been raised by the steam of initial pressure, but if we consider the slowness with which steam already formed receives additional heat, and the small amount required to elevate the temperature of that in immediate contact with the surfaces to equilibrium, it will become evident to us that this cause is hardly worth considering.

INDICATOR DIAGRAMS.

Journal Franklin Institute.

Scale; 1 inch = 22½ lbs.

Vol. XLI, 3rd Ser. Plate V.

There is, however, a powerful cooling influence, entirely independent of the varying *temperatures*, and dependent only upon the varying *pressures*. It is that of evaporation from the surfaces. Let us suppose that the engine is running full stroke, and that when the steam enters the cylinder at the commencement of the stroke, the surfaces with which it comes in contact are slightly cooler than itself; condensation of a portion of the steam upon those surfaces is the only manner in which the metal can be heated to an equilibrium by the steam. They become therefore immediately covered with a dew-like film of water. This water retains the same *temperature* as that of the steam with which it is in contact, and which it would itself have shown before its condensation, the *latent heat* only of the vapor condensed, entering the metal of the cylinder. Further, when the piston commences to move, it exposes to contact with the steam, the concave surface of the cylinder which had just previously been exposed to the lower pressure and temperature on the other side, and condensation takes place upon this surface as it is uncovered by the piston throughout the stroke, so that when the piston has arrived at the end of the stroke and the cylinder is full of steam of initial pressure and temperature, its whole interior surface is covered with a thin film of water at exactly the boiling point due to that pressure. When the exhaust valve opens and the pressure falls to that of the back pressure, the temperature necessary for water to boil, falls with it. In the case of the experiments, the temperature of the water condensed under the pressure of the entering steam, was 120° Fahr. higher than the boiling point of water under the back pressure. This water, therefore, immediately evaporates, converting into the latent heat of the vapor formed, not only the surplus temperature contained within itself, but also that which had been imparted to the metal of the cylinder at the time of its condensation. In this case all the heat thus robbed from the cylinder, and which must be returned to it by a new condensation at the next stroke, goes off to the condenser and is a total loss.

In the case, however, of using steam expansively, this is modified; for, as soon as the cut-off valve has closed, the pressure commences to fall, and, although condensation upon the surfaces continually exposed by the piston still goes on, as in the case of maintaining the initial pressure to the end of the stroke, the water which had been condensed under the higher pressure commences to evaporate as soon as this pressure commences to fall; and this re-evaporation goes on throughout the remainder of the stroke of the piston, so that the whole interior of the cylinder upon the steam side of the piston is being cooled down by evaporation from its surfaces, from the moment the cut-off valve is closed until the steam is again admitted to that side of the piston. The steam resulting from this re-evaporation before the end of the stroke is measured, of course, by the indicator, and is not accounted for by the quantities on line 25 of the table; and as during that portion of the stroke which was made by the piston while each particle existed in the form of water, such particle did not exert any dynamic force; the loss in dynamic effect due to condensation within the cylin-

der is greater than is measured by its amount as given in the table; but not so great as is due to the total quantity therein condensed, which quantity was not determined by these experiments.

For the Journal of the Franklin Institute.

Particulars of the Steamer Wm. G. Hewes.

Hull built by Harlan, Hollingsworth & Co., Wilmington, Del. Machinery by Morgan Iron Works, New York. Owner, Charles Morgan. Intended service, New York to Galveston.

HULL.—Length on deck, 239 ft. 4 ins. Do. at load line, 234 ft. Breadth of beam (molded), 33 feet. Depth of hold, 10 ft. Do. to spar deck, 18 ft. Length of engine room, 76 ft. Frames—molded, 4 ins., sided, 1 in.—apart at centres, 16 ins. Sketch of shape, 1; depth, 4 ins. 16 strakes of plates from keel to gunwale; thickness of plates, $\frac{1}{2}$ to 11-16 in. Description of cross floors, 7, 18 ins. deep, 9-16 and $\frac{1}{2}$ in. thick. Depth of keel, 6 ins. Diameter of rivets, $\frac{3}{4}$ in.; double riveted. One independent steam, fire, and bilge pump. 3 bulkheads. 10 fore and aft keelsons, 18 ins. high T. Cabin on deck. Draft, forward and aft, 9 feet. Tonnage, 1477.45. Area of immersed section at load draft of 9 feet, 270 sq. feet. Displacement at load line, 1253 tons. Masts, two.—Rig, schooner.

ENGINE.—Vertical beam. Diameter of cylinder, 50 ins. Length of stroke, 11 feet. Maximum pressure of steam, 30 lbs. Cut off at half stroke. Maximum revolutions at above pressure, 18. Weight of engines, 190,000 lbs.

BOILER.—One—Return tubular, and of steel plates. Length of boiler, 21 ft. Breadth do., 17 feet. Height do., exclusive of steam chimney, 9 feet. Weight do., with water, 102,690 lbs. Number of furnaces, four. Breadth of do., 3 ft. 6 ins. Length of grate bars, 6 ft. 8 ins. Number of tubes, above, 92; flues, below, 8. Internal diameter of tubes, above, 5 ins.; flues, below, 19 ins. Length of tubes, above, 15 ft.; flues, below, 11 ft. 4 ins. Grate surface, 93.09 sq. ft. Heating surface, 2600 sq. ft. Diameter of smoke pipe, 5 ft. 8 ins. Height of do., above grates, 50 feet. Consumption of fuel per hour, 1680 lbs.

PADDLE WHEELS.—Diameter over boards, 30 ft. Length of blades, 7 ft. 6 ins. Depth, do., 20 ins. Number do., 26.

Date of trial, December, 1860.

C. H. H.

For the Journal of the Franklin Institute.

Particulars of the Pilot Boat Wm. H. Aspinwall.

Hull built by Messrs. J. D. & J. B. Van Deusen, foot of Sixteenth Street, East River, New York. Owners, Messrs. Geo. Berger, John N. Dale, Gideon Mapes, Wm. A. Anderson, and Capt. Walter Brewer,—all New York pilots. Intended service, Harbor of New York.

HULL.—Length of keel, 74 feet. Do. on deck, 80 ft. Breadth of beam, 19 ft. 6 ins. Depth of hold, 8 ft. 9 ins. Draft, forward, 6 feet; aft, 9 ft. 6 ins. Keel, 22 ins. deep; also, a rocking keel of 12 ins. Tonnage, 100 tons.

MASTS.—Length of fore-mast, 76 feet. Do. main mast, 77 feet. Do. main boom, 46 feet. Do. fore gaff, 20 feet. Do. main gaff, 21 feet.

Remarks.—The *Wm. H. Aspinwall* cost \$8000. Her cabin is