Hence the compressibility of water varies according to the same law with that of a gas.

To express the law symbolically, let δ represent the fraction by which unity of volume of water is compressed by a pressure of one atmosphere, D the density of the water, its maximum density being taken as unity, and τ the temperature measured from the absolute zero; then

$$\delta = \frac{1}{K\tau D}.$$

K is a constant coefficient, the value of which is—

For the Centigrade scale, 72 atmospheres per degree.

For Fahrenheit's scale, 40 atmospheres per degree.

The following table exhibits a comparison between the results of the formula and those of M. Grassi's experiments. It will be observed, that the discrepancies are extremely small, and follow no regular law, being sometimes positive and sometimes negative.

The value of the single constant in the formula K was deduced from the mean of the first and second experimental results. The values of the density D were computed by means of the empirical formula in my paper On the Expansion of Liquids, published in the Edinburgh New Philosophical Journal for October, 1849.

Temperature. Centigrade from the ordinary zero.	Compressibility of water per atmosphere of pressure.		Differences.
	Calculated.	Observed.	
0°	0.000050584	0.000050560	—0.000000024
10.8	0.000048679	0.000048705	+0.000000026
13.4	0.000048252	0.000048378	+0.000000126
15.5	0.000047915	0.000047745	—0.000000170
25.9	0.000046353	0.000045843	—0.000000510
34.8	0.000045140	0.000045573	+0.000000433
43.0	0.000044158	0.000044414	+0.000000256
53.3	0.000042931	0.000044336	+0.000001405

As it has not yet been ascertained whether this law is applicable to other liquids and to water at higher temperatures, I refrain for the present from drawing any theoretical conclusions from it.

London, March 1851.

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Notes on the U. S. Tug Steamer "Engineer." By B. F. ISHERWOOD,
Chief Engineer U. S. N.

The "Engineer" is a small tug steamer attached to the Gosport Navy Yard, Va. The following particulars may be of advantage in the way of steam statistics:

Hull.—Length between perpendiculars, 105 feet; beam, 17 feet 2 inches; depth of hold, 6 feet 11 inches; mean draft, 4 feet 6 inches; depth of keel, 6 inches; thickness of bottom plank, 2 inches; of wales, 3

inches; of siding frames, 4 inches at head and 8 inches at heel. Area of immersed amidship section, 61 square feet.

Engine.—One beam engine; diameter of cylinder 25 inches; stroke of piston, 7 feet; space displacement of piston per stroke, 23,863 cubic feet.

Paddle Wheel.—Of the common radial kind; diameter from outside to outside of paddles, 17 feet; length of paddle, 4 feet 3 inches; width of paddle, 1 foot 6 inches; thickness of paddle boards, $1\frac{3}{4}$ inches; number of paddles in each wheel, 14; wooden arms, $6\frac{1}{2}$ inches by 3 inches; immersion of lower edge of paddles, 29 inches; paddle-wheel shaft of cast iron, $6\frac{5}{8}$ inches diameter in main journal; area of one paddle, 6.375 square feet; number of paddles immersed in each wheel, 3.

Fig. 1, cross section through flues. The straight lines show the connexion under smoke pipe.

Fig. 2, elevation—section through furnace.

Fig. 3, longitudinal section through flues.

Boiler.—One iron boiler of the “double return drop flue” variety, 17 feet long, $7\frac{1}{4}$ feet diameter, with a steam chimney $5\frac{1}{2}$ feet diameter, by 4 feet high above top of boiler; smoke pipe $2\frac{1}{2}$ feet diameter, and 31 feet high above the top of steam chimney; two furnaces, 3 feet by 5 feet each; total fire grate surface, 30 square feet; heating surface in furnaces, 128 square feet; in flues 326 square feet; in connexions 62 square feet; total heating surface, 564 square feet; proportion of grate to heating surface, 1 to 18.8; proportion of grate surface to space displacement of piston, 1.257 square feet per cubic foot; proportion of heating surface to space displacement of piston, 23.631 square feet per cubic foot; capacity of steam room, 212 cubic feet, or 8.884 cubic feet per cubic foot of piston displacement.

Calorimeter, or cross areas of flues at bridge	5.936 square feet, or 1 to	5.056 of grate-
“ “ “ middle flues,	4.746 “ “	6.321 “
“ “ “ back connexions	3.529 “ “	8.501 “
Area of smoke pipe, - -	4.908 “ “	6.113 “

With these proportions, the boiler furnishes steam for 20.9 double strokes of piston per minute of 21.8 pounds boiler pressure above the atmosphere, with wide throttle, burning 724 pounds of Virginia bituminous coal per hour with natural draught, cutting off at half stroke. Using dry Virginia pine wood, the boiler furnishes steam for 25 double strokes of piston per minute; of 30 pounds boiler pressure above the atmosphere, with wide throttle, burning half a cord per hour, cutting off at half stroke.

The cutting off was effected by an ordinary throttle valve placed in the steam pipe, and worked by a cam-board, operated by a cam on the main shaft. The cubic contents between the cut off valve and the commencement of the stroke of the piston, including clearance, was 2.02 cubic feet. Cutting off at half stroke, there was consequently used at each stroke of piston 13.95 cubic feet of steam. Taking the case in which coal was burned, when 724 pounds of coal per hour gave 20.9 double strokes of piston per minute of steam of 21.8 pounds boiler pressure above atmosphere, and supposing the initial pressure of steam in the cylinder to be two pounds less than in the boiler, or at a total pressure in the cylinder of 34.5 pounds, there would be evaporated per hour $13.95 \text{ cubic feet steam} \times 41.8 \text{ strokes of piston} \times 60 \text{ minutes} = 34986.6 \text{ cubic feet of steam}$. The relative volumes of steam and water at a steam pressure of $34\frac{1}{2}$ pounds is $777\frac{1}{2}$ to 1, and $\frac{34986.6}{777.5} = 44.999$

cubic feet of water. Taking the cubic foot of sea water at 64.3 pounds, $44.999 \times 64.3 = 2893.434$ pounds of sea water evaporated per hour by 724 pounds of coal, or 3.996 pounds of sea water per hour per pound of coal; to this must be added the loss by “blowing off” at a saturation of $\frac{3}{32}$, which is $11\frac{8}{10}$ per cent. of the total caloric, or 13.38 per cent. of the caloric utilized, and $3.996 \times 0.1338 = 0.535$ and $3.996 + 0.535 = 4.531$ pounds; a very low result, marking a badly proportioned boiler.

In the engine’s log from which the above facts are obtained, there is recorded, “the smoke is very black, and fell to the surface of the sea at 16 or 18 yards from the smoke pipe,” evidencing a very imperfect combustion; and in a letter from the engineer of the vessel, he remarks, “the draft is remarkably strong,” a fact which might have been inferred from

the low proportion of heating to grate surface, viz: 18·8 to 1', which being insufficient for the proper absorption of the caloric from the heated gases, they were delivered into the chimney at a very high temperature; and also from the large consumption of coal per square foot of grate surface, viz: 24·13 pounds. The quantity of clinker formed per hour, was 93 pounds, or 12·43 per cent., an excessive quantity, caused by the high temperature of the furnace resulting from the combustion of so large an amount of coal per square foot. The amount of ashes per hour, was 67·7 pounds, or 9·35 per cent. of the fuel. The amount of sea water evaporated per hour, per pound of coal per square foot of heating surface, was 6·864 pounds, inclusive of the loss by "blowing off," which is altogether too much for the economical use of fuel. In another part of the letter above referred to, from the engineer of the vessel, he says in reply to the question: Does the boiler foam? "Never under ordinary circumstances," which might have been deduced from the consideration that the steam room of the boiler contained 17·768 charges of steam for the cylinder, cutting off at half stroke. The data used in these notes are the mean of 40 hours continuous steaming in Chesapeake Bay, in July, 1849.

The quantity of atmospheric air chemically required for the complete combustion of one pound of bituminous coal, is 150·35 cubic feet. Of this amount, 44·64 cubic feet combines with the gases evolved by the heat from the coal, and the remaining 105·71 cubic feet combines with the solid carbon of the coal. Chemical experiment shows that when the gases (principally hydrogen and oxygen) are combined, the resulting mass is to the mass of atmospheric air required to furnish the oxygen as 10 to 11. The 44·64 cubic feet must therefore be increased in this proportion, and will become 49·104. The gases resulting from combination of the solid carbon and the oxygen, viz: carbonic acid and nitrogen gases, are of exactly the same bulk as the atmospheric air required to furnish the oxygen, viz: 105·71 cubic feet. The total masses then of atmospheric air and gases, will be $49·104 + 105·71 = 154·814$. This, it must be remembered, would be the mass of the products of combustion in a *cool* state, and would be expanded by the heat of the furnace into a greater mass. The ordinary heat of a furnace has never been accurately ascertained, but is commonly estimated at about 1000° F., and as the permanently elastic gases follow the law of Mariotte, and expand about $\frac{1}{436}$ th for each increment of one degree F., of temperature, it follows that the 154·814 cubic feet could be about trebled, or become 464·442 cubic feet. Taking the velocity of draft from Ure's experiments, at 36 feet per second, or 129600 feet per hour, (a high velocity,) there would be required to pass off 464·442 cubic feet, $\frac{464·442}{129·600} = 0·00358$ square feet

per pound of coal, and for 724 pounds, 2·592 square feet. This calorimeter or area of flue would therefore be required, provided a complete combination of the components of the coal and the oxygen of the atmosphere were obtained. Nothing like a complete combination, however, is obtained in practice; but from the experiments of Walter R. Johnson, De la Beche, and others, it appears that about 50 per cent. of the oxygen admitted into the furnaces of steam boilers, passes off uncombined.

The above obtained calorimeter should therefore be increased in the proportion of 150.35 to 309.628, or become 5.337; but it was actually at its minimum only 3.529 square feet, or *one-third less than it should have been*. The consequence was, as might have been predicted, a very imperfect combustion, and a shower of uncombined carbon falling at a few rods from the smoke pipe.

The inferior result obtained from this boiler, may be evidenced by the result obtained by Walter R. Johnson, from Virginia bituminous coal used in an experimental boiler. He obtained a mean evaporation of 7.27 pounds of fresh water per pound of coal.

We will now ascertain the result obtained in the boiler of the "Engineer," from the use of dry Virginia yellow pine wood. In the previous notes, it is stated that half a cord of this wood would maintain a steam boiler pressure of 30 pounds above atmosphere, giving 25 double strokes of piston per minute, cutting off at one half. As there would be 13.95 cubic feet of steam used per stroke, there would be used per hour $13.95 \times 50 \times 60 = 41850$ cubic feet; taking the initial pressure of the steam in the cylinder at two pounds less than in the boiler, we have a total steam pressure of $28 + 14.7 = 42.4$ pounds. The relative volumes of steam and water at this pressure are 643.4 to 1, and $\frac{41850}{643.4} = 65.045$ cubic feet of water. Taking the cubic foot of sea water at 64.3 pounds, $65.045 \times 64.3 = 4182.393$ pounds of sea water evaporated by half a cord of wood. The mean weight of dry yellow pine wood per cord as piled, is about 2600 pounds, and $\frac{4182.393}{1300} = 3.217$.

Adding to this the same per centage as before, for loss by "blowing off," viz: 13.38 per cent. of the caloric utilized, we have $3.217 \times 0.1338 = 0.430$; and $3.217 \times 0.430 = 3.647$ pounds of sea water evaporated per pound of wood. The evaporation per pound of coal being 4.531 pounds it follows that for equal weights, the coal is more efficient in the proportion of 1.242 to 1.000. From these figures, it also appears that the efficiency of one ton of Virginia bituminous coal of 2240 pounds, compared to that of one cord of Virginia dry yellow pine wood of 2600 pounds, is as 2782.08 to 2600.00, or as 1.07 to 1.00.

Performance.—The "Engineer" ran in Chesapeake Bay 360 miles in $39\frac{1}{2}$ hours, or at the rate of 9.057 miles per hour. Double strokes of engine per minute, 20.9. Steam pressure in boiler above atmosphere, 21.8 pounds. Back pressure in condenser, 2.2 pounds; cut off at half stroke of piston. Supposing (which will be very near the truth as found in practice), that the initial steam pressure in the cylinder is two pounds less than in the boiler, we shall have a total initial steam pressure in cylinder of $(21.8 - 2 + 14.7 =) 34.5$ pounds. Half the piston space displacement per stroke is 11.93 cubic feet, and the space comprised between the cut off in the steam pipe, and the piston at the commencement of the stroke, including clearance, is 2.02 cubic feet, making a total of 13.95 cubic feet of steam to be expanded into $(13.95 + 11.93) 25.88$ cubic feet: $\frac{25.88}{13.95} = 1.855$, the hyper. log. of which is 0.6179,

and $0.6179 \times 11.93 = 7.3715$, and $1 \times 13.95 = 13.95$, and
 $\frac{7.3715 \times 13.95}{23.863} = 0.894 =$ average effect of steam throughout stroke

of piston, and $34.5 \times 0.894 = 30.84$. Allowing the back pressure in the cylinder to exceed that in the condenser by 2 pounds, as found in practice, there would be a back pressure on the piston of 4.2 pounds to be deducted, leaving $(30.84 - 4.2) 26.64$ pounds as the mean effective pressure per square inch on the piston throughout the stroke.

The area of the piston being 490 875 square inches, and its stroke 7 feet, the horses power developed by the engine will be as follows:

$$\frac{490\,875 \times 26.64 \times 41.8 \times 7}{33000} = 115.95 \text{ horses power.}$$

The circumference of the circle of the centre of resistance of the paddles is 50.391 feet, and

$$\begin{aligned} 50.391 \times 20.9 \times 60 &= 63190.31 \text{ feet} = \text{speed of centre of reaction of paddles per hour.} \\ 9.057 \times 5280 &= 47820.96 \text{ " " " vessel per hour.} \end{aligned}$$

$$\frac{63190.31}{47820.96} = 1.3214 \text{ " " " slip of centre of reaction of paddles per hour.}$$

Or at 24.32 per cent.

The loss of labor from the oblique action of the paddles on the water, calculated as the squares of the sines of the angles of incidence, is 13.07 per cent.

Estimating the power required to work the engine at 2 pounds per square inch of piston, for an engine of this small size and great steam pressure, we have 7.51 per cent. of the total power thus consumed.

Taking from the experiments of Morin on friction 0.075 for the coefficient of friction for the load, and deducting first from the total mean effective pressure on the piston per square inch, viz: 26.64 pounds, the 2 pounds for working the engine, there remains 24.64 pounds, 0.075 of which is 1.848, and 1.848 is 6.94 per cent. of 26.64; 6.94 is therefore the per cent. of the total power developed by the engine, consumed in the friction of the load.

Collecting the above, we have the following:

Disposition of the power.

Slip of the centre of reaction of the paddles, 24.32 per cent, or 28.20 horses' power.			
Oblique action of the paddles,	-	13.07	" " " 15.15 " "
To work the engine,	-	7.51	" " " 8.71 " "
Friction of the load,	-	6.94	" " " 8.05 " "
Leaving to be utilized in the propulsion of the vessel,	-	48.16	" " " 55.94 " "
Totals,		100.00	115.95

The "Engineer" can tow a frigate at the rate of $2\frac{1}{2}$ miles per hour. She is badly proportioned for a Tug, her wheels having too great a diameter for the power, consequently opposing too great a leverage for the engine to at all develop the power of the boiler, while at the same time, the paddles have altogether too little immersed surface to obtain the necessary resistance in towing; a great waste of effect in slip, is the inevitable result.