W Richardson

Dudley

AN ESSAY

ON

THE BOILERS

OF

STEAM ENGINES:

THEIR

CALCULATION, CONSTRUCTION, AND MANAGEMENT,

WITH A VIEW TO THE

SAVING OF FUEL.

INCLUDING

OBSERVATIONS ON RAILWAY AND OTHER LOCOMOTIVE ENGINES, STEAM NAVIGATION, SMOKE BURNING, INCRUSTATIONS, EXPLOSIONS, ETC., ETC.

BY R. ARMSTRONG,
CIVIL ENGINEER.

A NEW EDITION,

CONSIDERABLY ENLARGED AND IMPROVED.

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1839.

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TO

JOHN DALTON,

D.C.L., LL.D., F.R.S. L. AND E., ETC., ETC., ETC.

THIS FIRST ATTEMPT

TO COLLECT THE PRACTICAL RESULTS OF A NEW AND IMPORTANT BRANCH

OF

CHEMICO-MECHANICAL ENQUIRY,

IS,

WITH EVERY SENTIMENT OF RESPECT AND GRATITUDE,

INSCRIBED

BY HIS OBLIGED FRIEND,

THE AUTHOR.

PREFACE.

THIS Essay having already experienced a very favourable reception at the hands of those practically engaged in steam engineering, and therefore best qualified to judge of its merits, I have been induced to make considerable additions and improvements in this edition, with a view to make it more worthy the patronage of the public generally.

I am fully aware that the unexpectedly rapid sale which this book has met with, cannot in justice be ascribed to any peculiar quality in the performance itself, but rather to the well-known fact, that complete works from the hands of practical men, on this and some collateral subjects, were very much wanted.

This consideration has determined my intention to follow up the general subject in a series of theoretical and practical essays on the production and application of steam as connected with engineering and mechanical purposes, each work to be about the same size and price as the present.

The next of the series is intended to be on the *Chimneys* of steam engines, and will include rules for the proper construction and arrangement of the flues and furnaces of steam boilers generally, so as to insure a good draught. This proposed work is not so much intended to be a complete guide in *all* the details of construction, as it will be a practical assistant to the employer, the capitalist, or the man of science;

and still less is it meant to encroach on the province of the architect in anything regarding beauty of design or embellishment, any more than the present can be considered as interfering with the business of the professed boiler-maker or experienced engineer.

My principal object in this, as it will be in future essays, is to collect and arrange data from the practice of the best engineers and builders as found in their works, free and unprejudiced by any previously formed theoretical views whatever, and at the same time perfectly unconnected with any particular *shop* or individual tradesman, so that a fair comparison may be made; and in order that rules may be obtained for the guidance of the master manufacturer, as well as to simplify the various processes of calculation required by the working mechanic.

In attempting the accomplishment of the above objects, it has been deemed expedient to confine the scope of the present volume as much as possible to the general practice that is found within a range of thirty to forty miles round Manchester; but, with a few alterations in the rules and formulæ, easily made, and which are pointed out where necessary, the latter will be found equally applicable in any other part of the kingdom.

Although *locomotive* and *marine* boilers are only incidentally treated of, they being thought of sufficient importance to require an essay exclusively to themselves, yet the principles evolved in the present work will be found to be a necessary groundwork towards forming plans for their future improvement, they being comparatively recent inventions as compared to the ordinary land boilers, which have been the subject of experiment and observation for more than a century; hence the necessity that the elements (at least) towards a settled theory of the latter should precede any satisfactory investigation of the former.

For similar reasons to the above, some of the details which do not essentially affect the construction or calculated power of a boiler, are omitted, or only slightly touched on. The various kinds of feeding apparatus for coal and for water; steam gauges and water gauges; cleansing apparatus for the boiler and for the furnace, the fire-grate and the flues; safety valves and safety pipes, and other accessories, afford abundant matter for two or three such volumes as the present.

To the cotton manufacturers, and other proprietors of steam-engines generally, in Lancashire, my grateful acknowledgments are particularly due, for the many opportunities for improvement which they have afforded me during several years in obtaining constant access to, and personal inspection and examination of, every thing concerning their engines and boilers.

Of the value and variety of information so obtained, it needs only to be stated, that Manchester alone is supposed to contain at the present time at least double the amount of steam power of any other town in the world. Within the boroughs of Manchester and Salford there are 400 steam engines of about 10,000 horse power, but working at 12 or 14,000, and within six or eight miles round, there are at least about 10,000 horse power more, working up to 15 or 16,000. The total consumption of coal for this purpose, within a semicircle of seven miles radius from Manchester Exchange, is about 20,000 tons per week.

In a district where such facilities exist for obtaining correct data in so important a branch of physical science, and at a period when the almost illimitable powers of the steam engine are being developed for railway and marine purposes to an extent so perfectly unprecedented, that minds the least imbued with enthusiasm are forcibly impressed with the belief that the age of invention and improvement is yet but in its infancy, it is but natural to expect that the establishing of a system of steam engineering upon facts, rather than upon theoretical principles, should be considered an object highly worthy of attainment. If, in furnishing materials towards such ulterior object, this attempt be considered only as that of a useful practical pioneer, my present purpose will be fully accomplished.

The additions to this edition are principally as follow:

1. In Chapter III. (Art. 119 to 143,) I have introduced a new theory on the comparative durability of iron and copper boilers, as used for locomotive and marine engines, grounded on recent experiments made with her Majesty's steam ships in the Mediterranean, by Mr. Dinnen, Assistant Engineer, Royal Dock-yard, Woolwich. To this gentleman I am under considerable obligations, not only for his excellent paper on Marine Boilers, in Weale's edition of Tredgold, which first induced me to remodel this Essay, but also for recent valuable private communications of facts and observations, (accompanied with a series of specimens of boiler scale from various parts of the world,) which have been the means of considerably modifying some opinions which I previously held on this and other subjects, and which I have endeavoured to make in part available in this work. I therefore, with much pleasure, take this opportunity of recording my sense of his valuable assistance.

2. In the same Chapter, (Art. 152 to 159,) will be found a new theory of some variations in the temperature of the boiling point, containing an explanation of the previously unaccounted for experiments on that subject by Dr. Bostock and M. Gay Lussac, and which was briefly alluded to in the last edition.

3. The *fourth* chapter is almost entirely a new one. In addition to some theoretical views that were given in the fifth chapter of the last edition, it contains various tables of dimensions, calculated for the practical use of the engineer and boiler-maker in the designing of new boilers, together with the mathematical investigations on which they are based.

These tables form the principal feature in the additions of a practical character. They are portions of some that I calculated several years ago with considerable labour, and which I purposely withheld on the first publication of this work, from an idea, whether well or ill founded, that, as the information they contained had, while confined to myself, already mainly assisted in establishing a considerable practice in that particular branch of my professional business to which they relate, it was not in accordance with good policy to give to the public at once, without a fair expectation of some recompense, that which was of considerable value to myself individually. This feeling was considerably strengthened by an assurance from my then publisher, that only about one book in ten pays its own expenses. The case, however, is now changed by the sale of two impressions within twelve months, a circumstance which surprised none more than myself, and of course unexpectedly made me a debtor to the public, an obligation which I take this means of endeavouring, in part, to repay.

4. In the same chapter I have also added an account of some evaporation experiments, which are respectfully offered to the notice of those who have been recently engaged with similar experiments in Cornwall.

5. The *fifth* chapter is so much of the fourth of the last edition as related to the important subject of deposit and incrustation, to which is now added the latest information relating to the subject.

6. The *sixth* chapter is on Explosions. A hope of doing good in assisting in any way in preventing a continuation of those calamitous occurrences which have lately attracted the notice of the legislature, and which (I am afraid must be admitted) are no less disgraceful to the engineering improvements of the present time, than they are shocking to

humanity, has induced me to considerably extend this chapter.

Regarding the subject of explosions, I am convinced that much more remains to be done than seems yet to have been attempted. If the suggestions I have deemed it expedient to make be considered of any utility, I shall probably pursue the subject in a future publication with such aids as may be derived from the forthcoming Report of the Commissioners lately appointed by government to investigate so much of the subject as relates to steam vessels. There are, however, small hopes of much enlightenment on the general subject from the present Commission, owing to its labours being (as is understood) confined *exclusively* to that branch of the enquiry belonging to marine boilers. It is perhaps true that extra-legislative interference with land boilers might possibly do more harm than good; yet a co-examination of the prominent facts relating to explosions with factory and colliery boilers, unincumbered with such complicated circumstances as must necessarily occur on shipboard, would certainly have been of considerable assistance in carrying on the enquiry upon sound principles.

Although I have been for a series of years constantly engaged in nearly all the practical operations connected with the general subject of this work, it would be in vain to deny that I have latterly received most material assistance from various quarters, but least of all from books. Consequently if in adopting the verbal information of others any erroneous statements occur, I shall confidently trust them to the candour and liberality of the reader, and shall receive with gratitude the correction of any error that can be pointed out, and also make the best use of such corrections with proper acknowledgments in future editions.

In the mathematical and physical sciences there *ought* to be no room for prejudices, they not admitting of any medium between right and wrong; therefore if in the following pages any opinions are to be found expressed in too positive a manner, I hope the latter will be placed to the account of an excusable zeal for the dominion of truth over error. I have no desire to deserve the charge occasionally made by practical men against some authors on kindred subjects to the present, namely, that the latter seem so afraid of getting wrong that they very seldom get right, and thereby embarrass themselves and their readers by copying and collating one another's errors, apparently satisfied if they can only refer to any book authority for them. For my own part, I have always thought that more harm has generally been done by propagating an error than in the first committing of it; consequently I shall as cheerfully and positively denounce my own errors as those of others.

Respecting any new schemes or suggestions of his own, it is always difficult for an inventor to speak with becoming humility. However, if in my own case allowances must be made, I hope at any rate to be found impartial in analysing the schemes of others. But I have no wish to avoid the responsibility attaching to any thing I have advanced in the following pages, although I prefer that my views and opinions may be tested by facts and the experiments of others, rather than be taken as authority from me; and those who are *pecuniarily* interested in this matter generally have the means of doing so constantly at hand.

To conclude: in claiming indulgence for probable errors in matter of graver import, it will not, perhaps, be thought too great a stretch of the critic's charity, if extended to the literary defects which I am conscious this work must of necessity contain, more especially when I state that up to a comparatively late period of life I have been more accustomed to handle the hammer than the pen. And moreover I may express a hope, that as mere literary deficiencies cannot much impair the utility of my work in the estimation of those for whom it is more particularly designed, they will not be allowed to operate in preventing its continued kind reception by the public generally.

R. A.

Pendleton, near Manchester,
June, 1839.

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ERRATA.

Page 3, line 2, *for* three *read* four.

Page 32, line 18, *read* Mr. *William* Horrocks.

Page 85, line 6 from the bottom, *for* of the day, *read* of his day.

Page 89, lines 22 and 32, *for* Horrocks, *read* Horrockses.

Page 90, line 27, *for* 55 inches diameter each, *read* 50½ inches diameter and 8 feet stroke.

Page 92, art. 111, *for* Gauge point, *read* Divisor, *in every instance.*

Page 93, art. 113, correct the examples, &c., at the places indicated, as follows:—

"Horse power=101."

"Diameter of cylinder, 50½ inches."

"a velocity of 264 feet per minute."

"found horse power 101."

"Is to the real speed 264." "*nominal* horse power=120."

Page 94, line 3, *for* nine pounds, *read* ten pounds.

Correct the example thus:—"*nominal* horse power 120."

"Is to the real pressure 10." "*indicated* horse power 200."

Page 111, last line but one, *for* Fife, *read* Fyfe.

A

PRACTICAL ESSAY

ON

STEAM BOILERS,

ETC., ETC.

CHAPTER I.

GENERAL REMARKS, WITH METHODS OF MEASURING THE HEATING SURFACE, AND PROPORTIONING THE AREA OF FIRE-GRATE.

1. WE may generally premise of any of the Arts, where mechanical construction is concerned, that while yet in their infancy, or in a state just emerging from that of mere rude invention, and when there has not been time to observe a sufficient number of facts from which to deduce general principles, a great multiplicity of contrivances must be the natural consequence. As a remarkable illustration of this, witness the Steam Engine itself, which in the hands of Smeaton, Watt, and others, successively assumed such a variety of forms, until the last-mentioned great improver left it in all the leading principles of its construction—a monument of perfection in mechanical science.

With all the recent discoveries in Chemistry and the phenomena of heat, it is not surprising that the *primum mobile* of the Steam Engine, the *Boiler*, should become an interesting source of speculation to patentees, and schemers of all kinds. Until within the last twenty years, the steam boiler received a very small share of attention from engineers; the immense efforts made by them in improving the engine itself, previous to that period, seemed to absorb all their inventive talent, and it is only since the commencement of the present century, when the manufacture of engines had become settled on something like scientific principles, that the making of steam engine boilers became a regular trade.

Consequent on Mr. Watt's great improvements, the application of the power of steam to factories became a matter of course, and it is considered that rival manufacturers have been the means of giving an impulse to the progress of invention in all that concerns the steam engine, as well as in the application of steam to other purposes, which it could not otherwise have obtained; for when their invention had exhausted itself in other departments, they naturally turned their attention to the object of diminishing the expense of fuel used in generating the steam, and to the general economy of their engines and boilers.

Without venturing an opinion on the assertion of M. Pambour, in the introduction to his excellent treatise on Railway Locomotive Engines, namely, that the theory of the steam engine itself *has not yet been explained* *, we may with much truth affirm, that with respect to the steam boiler his words are much more applicable, however successful may have been the practice of individuals. Consequently it is not surprising that a great variety of opinions are held on the subject. This difference of opinion relates not only to the shape of boiler best adapted to supply the greatest quantity of steam with the least expenditure of fuel, but also to its dimensions or capacity suitable for an engine of a given number of horses

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* A Practical Treatise on Locomotive Engines upon Railways. By the Chev. F. M. G. Pambour. London, 1836.

power; this latter question we propose to consider principally in the first three chapters of this essay.

2. The only rule for adjusting the dimensions of boilers, if rule it be, that is generally agreed on amongst engine and boiler makers, is to endeavour to have them larger than necessary—hence it has become a common observation, that a ten horse engine ought to have a twelve or fifteen horse boiler, or a twenty horse engine ought to have a thirty horse boiler, and so on. It is true that some vague notions have long existed amongst working engineers, as well as with some writers on the subject, that there ought to be about five square feet of surface of water, or of the largest horizontal section of the boiler, for each horse power, and about twenty-five cubic feet of space for the same. The first of these data has become common amongst enginemen as their only acknowledged rule for roughly estimating the power of a boiler, although both it, and the mode of estimating by the cubic capacity, have generally been scouted by scientific engineers, but with how little reason, while the latter could not furnish us with better methods, we shall see in the sequel.

After consulting the works of Farey*, Tredgold†, and others who have treated on this subject, besides discussing the matter with various eminent scientific persons, as well

* A Treatise on the Steam Engine, Historical, Practical, and Descriptive. By John Farey. London, 1827. Vol. I., quarto.

† The Steam Engine, comprising an Account of its Invention and Progressive Improvement, with an investigation of its Principles, &c. By Thos. Tredgold. London, 1827. Quarto. A second edition of this Work, edited by Mr. Woolhouse, with a very valuable Appendix, has just been published, 1838. Of this edition, as illustrating the recent Progressive Condition of Steam Navigation, it is impossible to speak too highly, enriched as it is by contributions from some of the most eminent practically scientific men of the present day. The latter portion, by far overbalancing any value that could be attached to the original work.

as experienced manufacturers, we were fully convinced of the necessity of obtaining and comparing a great number of experiments on a large scale and under a variety of circumstances, in order, if possible, to deduce rules that might at least be applicable to those forms of boilers in general use.

3. Amongst our earlier experiments, which were made on a smaller scale, was one with a common furnace-pot, or boiler, of cast-iron, such as are usually set in kitchens; it was capable of holding eighteen to twenty gallons; the fire-grate was six inches by eight, or one-third of a square foot in area, and the whole of the heating surface exposed was about three square feet. Into this boiler was measured two cubic feet of water, and after having caused it to boil, it was then found, that by feeding the furnace with coal and the boiler with water, and at the same time managing the draught of the chimney so as to keep the water boiling nearly at a uniform rate, the consumption of good coal was at the rate of four and a half pounds per hour, and the quantity of water boiled away in that time was exactly two gallons, or very nearly one-third of a cubic foot.

4. Now as it is usual to reckon that the evaporation of one cubic foot of water per hour is sufficient to furnish steam for one horse power, we have only to multiply each of the foregoing results by three to obtain the following proportions:—

1 cubic foot of water evaporated per hour, requires
1 square yard, or 9 square feet, of heating surface,
1 square foot of fire-grate, and
$13\frac{1}{2}$ lbs. of good coal.

We thus obtain what may be called a rough estimate of a boiler of one horse power, and with an expenditure of fuel approaching to the usual allowance of fourteen pounds of coal per horse, per hour. This experiment, which was frequently repeated, was made with an open-topped boiler, which induced us to make several other experiments with a variety of small boilers, more nearly assimilated to the condition of an ordinary steam boiler, attached to an engine at work; the results were, in all cases, whether under a pressure of four or five pounds per square inch, or open to the pressure of the atmosphere alone, so nearly agreeing with the above, that excepting increasing the quantity of water in the boiler, which seemed to increase the quantity of fuel used in getting up the steam, but at the same time lessened the other portion of the general consumption, by lessening the difficulty of regulating the fire, there was no other alteration that materially affected the results as given above.

5. It will be perceived, that there is a remarkable coincidence in the figures expressing the dimensions, and the effect produced, in the above experiment, which renders it extremely convenient for forming a unit measure of steam boiler power; for we have only to conceive a vessel, say a cube for instance of three feet square, or *a cubic yard* in capacity, with its lower side of *one square yard* in area, exposed to the action of a fire on a grate of *one square foot* in area—let this vessel be nearly half filled with water, and then after the steam is once got up, we have, by burning away 13 or 14 pounds of coal, one cubic foot of water converted into steam, equal to the pressure of the atmosphere, or a little above, and which, if well applied in a good Boulton and Watt engine, is well known to be fully equal to one horse power as usually reckoned, or, in other words, it will lift 150 lbs. 220 feet high in a minute, which is at the rate of 33,000 lbs. raised one foot high in the same time.

6. This is the measure of a horse's power as originally settled by Mr. Watt, and to which both Farey, Tredgold, and all other engineers of eminence have agreed to refer as a standard. And it may be as well here to remark, that this was no fanciful standard of Mr. Watt's, but really taken by him as the average power exerted by a mill horse travelling at the rate of 2½ miles an hour (or 220 feet a minute) and raising a weight of 150 lbs. by a rope passing over a pulley, as appears by Mr. Watt's letter to Dr. Brewster, published in the second volume of Dr. Robinson's Mechanical Philosophy, 1822. This standard horse power of Mr. Watt's ought not to be departed from, as it has the merit of simplicity and convenience to a great degree; for 150 lbs. being exactly divisible by 6, (which is supposed to be the number of pounds effective pressure per circular inch on the piston, most suitable for the best modern engines,) gives exactly twenty-five, which is the number of circular inches per horse power in Boulton and Watt's original forty horse engines, very nearly. Hence a cylinder of five inches diameter (=25 circular inches area) with an effective pressure of 6 lbs. per circular inch on the piston, if travelling at the rate of 220 feet in a minute, will give one horse power.

CONSUMPTION OF FUEL IN FACTORIES.

7. With regard to the usual allowance of 14 lbs. of coal, or one-eighth of a hundred weight, per horse per hour, it ought to be borne in mind that in practice (at least it is so in an average of the best regulated cotton mills in Lancashire) it is the *whole consumption*, including that used for getting up the steam, as well as to supply steam sufficient for warming the mill. One-eighth of a hundred weight per hour is equal to ten hundred weight, or half a ton for 80 hours, and as 80 hours is about the length of time that the boilers are at work during each week in cotton mills, we

may state generally that half a ton per horse power, per week, is the total average consumption.

8. Now to obtain the net consumption required by the engine alone, we have to deduct that used for heating the mill the amount of which depends upon a great many circumstances; but it is generally supposed that in the best constructed modern factories, it is not less than from 10 to 15 per cent. of the whole, and there is reason to believe, from estimates made of the quantity of condensed steam or steam water obtained from the pipes, as well as from accounts of coals kept where separate boilers are used for the purpose, that the average quantity of fuel required for steaming a cotton mill cannot be much less than 20 per cent. of the whole consumption; but if we take it at 15, it will leave $14-(\frac{15}{100}$ of $14 =)\ 2{\cdot}1 = 11{\cdot}9$ lbs. per horse per hour, for the consumption on account of the engine alone.

9. Again, the engine in a factory generally runs 69 hours per week, consequently our reckoning allows 11 hours during the week for getting up the steam after stoppages; or $1\frac{3}{4}$ hour per day ($=10\frac{1}{2}$ hours per week) with half an hour extra for Monday morning, making 11 hours, which is probably an average of the hundred and odd cotton mills in Manchester. Some persons estimate it at two hours per day; and if we consider that there is at least as much coal laid on per hour in getting up the steam, as is used per hour after, we cannot reckon less than 15 per cent. of the whole consumption for that purpose; but of course it depends almost entirely upon the quantity of water in the boiler. Therefore we have $11{\cdot}9$ less by $2{\cdot}1 = 9{\cdot}8$, or say nearly 10 lbs. per horse, per hour, as the net consumption of coal while the engine is at work.

10. We have been informed of some experiments lately

which gave the last mentioned item of expenditure as low as only *ten* per cent., although the boiler contained rather more than the usual quantity of water, but the draught was unusually strong, and from other circumstances the consumption of fuel was considerably above the average. It is difficult to come at the exact proportion used in cotton factories, on account of the consumption for this purpose being generally mixed up with that for steaming the mill before mentioned, and which is generally the greatest in a morning at the same time when the steam is being got up for the engine, consequently very great discrepancies of opinion are met with on this subject.

The proprietor of a fine spinning establishment once informed us that he had sometimes observed a mere shifting of the wind a few points of the compass, without any other alteration, to cause a difference in the quantity of coal consumed amounting to as much as a wagon load per day, and which could not be less than 10 per cent. of the whole of the coals used. On the other hand, some well informed managers and practical men have declared that in some cases where the mill is steamed from the same boilers which supply the engine, *and done properly*, the extra fuel required is so small as to be hardly of any account.

11. Hence it will appear that it is extremely difficult to procure exact data relating to the subject, although a matter of considerable importance in the economy of a cotton mill. We have had very little of a practical nature on this subject of any value since the publication of the essays of Mr. Robertson Buchanan in 1810*, so that a well conducted

* Practical and Descriptive Essays on the Economy of Fuel, and Management of Heat. By Robertson Buchanan, Civil Engineer. Glasgow, 1810.

set of experiments on this head are highly desirable at the present time, and particularly if accompanied by a parallel series of meteorological observations. It has been thought by some that allowing 15 per cent. for steaming the mill is overrating the average consumption, but we are convinced it is not, and this conviction is founded upon a great number of experiments; in one case, indeed, in one of the best regulated cotton mills in Manchester, where a separate boiler was kept solely for this purpose, and in this one would think there could be no mistake, the average of the year was about 20 per cent., or one-fifth of the whole consumption.

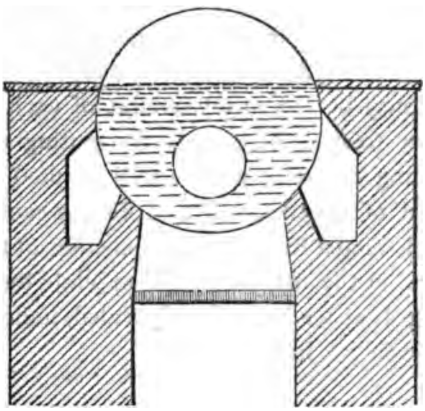
Whatever may be the exact amount of each of the items we have been treating of, namely, for getting up the steam and for heating the mill, we are well assured of the combined amount of the two, and that 30 per cent. at the least ought to be deducted from the gross amount of the coal used in order to get at the net consumption while the engine is at work, leaving it, as we have already stated, under ten pounds per horse power, per hour.

CYLINDRICAL BOILER.

12. The next boiler in point of size to the experimental one before mentioned, which we have had sufficient opportunities to observe, is of a cylindrical shape, a kind frequently used to high-pressure engines, and generally considered, as it certainly is, very safe and strong; its inside dimensions are as follow, (see Fig. 1,) five feet in diameter and nine feet in length with a cylindrical flue running through the lower part from end to end, of eighteen inches in diameter; the fire-grate is placed under the boiler at one end, it is three and a half feet square, or twelve and a quarter square feet area; the flame, or smoke, after passing from the fire and under the whole length of the boiler bottom, rises up at the farther end, and returns through the inside flue to the front end of the

boiler, where it is allowed to divide into two brick flues, one on each side, through which it is conducted along the sides of the boiler again to the back,—here the two currents unite and proceed in one main flue to the chimney. This method of dividing the current of smoke and hot air into two flues is called a "*split draught;*" and when it is continued round in the same direction it is called a "*wheel draught.*"—(See Art. 20.)

Fig. 1.



13. This boiler, according to the common horizontal measurement of five square feet of water surface per horse power, would be equal to nine horse power; but some engineers, who are in the practice of making this kind of *flued* boilers, or as they are frequently, although incorrectly, called *tubular** boilers, usually consider the diameter of the inside tube or flue as so much added to the width of the boiler—a mode of estimating its power which gives a result not far from correct, in cases like this, where the boiler is short in proportion to

* This term is more suited to the boilers of Woolf, Gurney, and others where the water is contained in the tubes, as distinguishing them from those where the tubes are used as fire-flues.

its width. In a very short boiler a great portion of the flame must act on the inside flue as effectually as it would have done on a continuation of the boiler bottom.

14. According to this rule, the power of the boiler is found as follows:—

		Feet.
Width or diameter of the boiler..........	=	5
Ditto of inside flue	=	$1\frac{1}{2}$
		$6\frac{1}{2}$
Multiply by the length		9
Divide by...................................	5)	$58\frac{1}{2}$
Horses power....................	=	$11\frac{3}{4}$ nearly.

15. The evaporation in this boiler was ascertained to be very regularly 10 to 11 cubic feet of water per hour, with very little less than 15 pounds of coal per cubic foot. It was attached to a high pressure engine called 12 horse power, and working with a pressure in the boiler of 30 pounds per square inch; but the engine was certainly, when at the best, not doing more than 10 horse power.

16. We shall now compare the dimensions of this boiler with the unit measure derived from the experimental boiler. (Art. 4.)

		Circular Feet.
Diameter squared, or 5^2...............	=	25
Deduct area of flue $(1\frac{1}{2})^2$	=	$2\frac{1}{4}$
Net area of boiler end.................		$22\frac{3}{4}$

This multiplied by ·7854...........	=	17·86 square feet,
Again multiplied by the length 9...	=	160·74 cubic feet,
Which divided by 27................	=	5·95 cubic yards

for the total capacity of the boiler; or, according to our assumed data, only sufficient for about 6 horse. If equally divided between steam and water, then, according to the work on the engine, there is $160{\cdot}74 \div 2 = 80{\cdot}37$ cubic feet, and $\div 10 = 8$ cubic feet of water per horse. But, as in the case of the experimental boiler, it was found that a greater proportion of water was more economical, as tending to balance any want of uniformity in the feeding of the fire, or in the action of the force pump which supplied the boiler with water, and on that account the quantity of water really worked with was about four cubic yards, or nearly eleven cubic feet per horse power.

17. The steam-room was thus of course diminished to about one-third of the capacity of the boiler; a space much too small for the proper working of even a 6 horse engine, as will be shewn hereafter; but this evil was in some measure remedied by a method of working which partially prevented the casual boiling over, or "*priming over*," of the water into the cylinder, although accompanied with a considerable deduction from the power of the engine, that is, by a process which is technically called "*wire-drawing the steam*," or, in other words, working the steam a great deal higher in the boiler than in the cylinder. This wire-drawing process has been much lauded by the advocates of high pressure engines, and steam carriage projectors, as an important discovery; it is however only an expedient to enable an engine to be worked with a little boiler, although at the expense of an increased consumption of fuel, and adding greatly to the danger of the boiler bursting.

18. The most important consideration that concerns the evaporating power of the boiler, is the quantity of *heating surface*, or surface exposed to the hot air. The usual method of estimating the *whole* of the surface exposed to the

hot air, as heating surface, has been a fruitful source of mistakes and misapprehensions among steam engineers, because, as heat is with difficulty made to pass downwards to any useful purpose, it is plain that such portions of the surface only as are exposed to the *upward* action of the flame and hot air ought to be considered as *effective heating surface* to its full extent. With regard to the upright or vertical portions of a boiler there may be a question, but it seems to be agreed to by every one who has attended to this subject, that at any rate the ordinary vertical or side surface is not more than one-half so effective as the *under* surface, and we have assumed this to be the ratio in the following calculation, which is inserted merely as an example of a method of computing the effective heating surface, which will be found to be sufficiently correct for practice when applied to the ordinary forms of boilers in general use in factories.

	Square Feet.
The area of the boiler bottom is $9 \times 3\frac{1}{2}$........	$= 31{\cdot}5$
The two sides together $= 1\frac{1}{2} \times 9 \times 2$..............	$= 27{\cdot}0$
The front end about 6·2, take one-half........	$= \ \ 3{\cdot}1$
The inside flue $= 1{\cdot}5 \times 3{\cdot}1416 \times 9 = 42{\cdot}4$; of this only the upper half can be considered as actual or effective heating surface..........	$21{\cdot}2$
	$82{\cdot}8$

This sum ÷ by 9 gives 9·2 square yards as the total effective heating surface of the boiler, which is less than one square yard for each horse power; but the area of the fire-grate is $12\frac{1}{4}$ square feet, which is more than one square foot per horse power: therefore, if we take the mean* of the two, or about $10\frac{1}{2}$ for the horse power of the boiler, it gives us

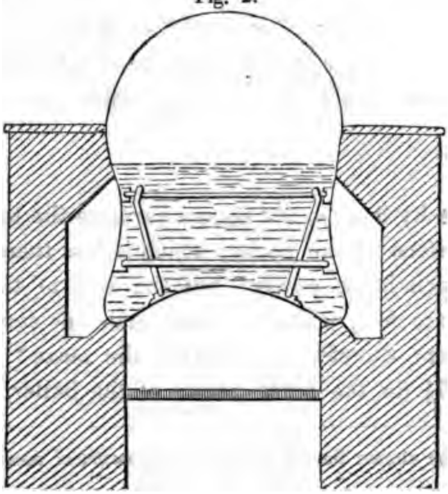
* It will be shewn hereafter that the *geometrical* mean ought to be taken.

about the same proportions as the data assumed in the experimental boiler, while the greater quantity of coal used may be accounted for by the much higher temperature to which the furnace requires to be kept, compared to that of a low pressure boiler.

WAGON-SHAPED BOILER.

19. In order to examine accurately the proportions that are generally adopted in practice, in connection with the common low pressure or condensing engine, it will be best to take an instance of a plain wagon-shaped boiler, without any inside flue, (see Fig. 2,) say twenty feet long, five wide, and six feet eight inches deep. This description of boiler is in very general use in this district, and with these dimensions it is called a twenty horse boiler, being well known to be fully equal to supplying steam for a twenty horse engine with the usual allowance of fuel. They are also frequently made from sixteen to twenty-four feet long, with the same depth and width, being considered as many horses power as feet in length.

Fig. 2.



20. In the furnace of the twenty horse boiler, the fire-grate is five feet long and four feet wide, or twenty square feet in area. The boiler is usually set up with what is called a *wheel draught*, that is, the current of flame, smoke, or other gaseous products of combustion, after passing under the boiler bottom, is made to rise up at the back end, and returning along one side by a brick flue to the front, crosses the front end, and repasses along the other side to the back, where it goes into the main flue which conducts it to the chimney.

The upper part of this boiler is a semi-cylinder and contains—

$$\frac{5^2 \times 20}{2} = 250 \text{ cylindrical feet,}$$

Or, $250 \times \cdot 7854 = 196 \cdot 35$ cubic feet.

The lower part, if made with straight sides and flat bottom, would be equal to $4 \cdot 1666 \times 5 \times 20 = 416 \cdot 66$ cubic feet; but the capacity of the lower part of the boiler is however reduced by about one-sixth, owing to the sides being made concave outwards, four or five inches on each side, for the purpose of strength, as well as for exposing the side surface in a better position for the action of the hot air, the bottom of the boiler being also arched upwards nine or ten inches with a similar view.

Therefore, $416 \cdot 66 - \dfrac{416 \cdot 66}{6} = 347 \cdot 22$ cubic feet.

And to this add the upper part $= 196 \cdot 35$

$543 \cdot 57$

Or $543 \cdot 57 \div 27 = 20 \cdot 13$ cubic yards, which is the real capacity of the boiler. One half of this space is allowed for water, and the other for steam, consequently, if we make some deductions for the space occupied by the stay bars, &c.,

which this shape of boiler necessarily requires for the sake of strength, nearly half a cubic yard is left for water room, and a little more for steam, for each horse power.

21. The depth of water is found as follows:—Take half the difference of capacity between the lower and upper part, and divide it by the area of the water surface, then deduct the quotient from the depth of the lower part of the boiler, and the remainder is the depth of water, taken perpendicularly over the seating plate at the bottom of the boiler. In this case—

Capacity of the lower part....................	347·22	cubic feet.
Ditto upper part....................	196·35	
2)	150·87	
Area of water surface ($=5\times20$) $=$ 1,00)	,75·43	= half diff.
	·7543	= quotient.
Subtract from depth of lower part.......	4·1666	
Remainder in feet .... =	3.4123	
	12	
And inches................=	40·9476	

Hence, three feet five inches nearly is the depth of the water required.

22. The brick-work of the side flues is gathered in, two or three inches below the surface of the water; hence, the depth of the side surface is about 3·25 feet, or measuring by the curved surface about 3·5 feet, and the total area $= 3{\cdot}5 \times 40 = 140$ square feet. The total area of the two ends below the tops of the flues is about 28 square feet—less by the area of surface covered by the brick arch over the furnace mouth (about 3 square feet) and by the brick-work at

the back end, which divides the " uptake," from the side flue, (about two square feet,) leaving about 23 square feet, which added to the side surface, gives 140 + 23 = 163 square feet for the total area of vertical surface; but, as we have already seen, only one-half of this can be considered as effective heating surface—it is only equal to 81·5 square feet, or 9·05 square yards. The area of the bottom, measuring by the curved surface, amounts to about 94 square feet, or 10·4 square yards, which is all effective; hence the total effective heating surface of the boiler is 19·45, or say nearly 20 square yards.

23. The kind of boiler just described has been in such general use for so many years, and in consequence has become so well known, that it will be useful to refer to it as a standard. Until within the last eight or ten years, the wagon boiler may be said to have been almost universal in the cotton district around Manchester; and it is believed that four-fifths of all the boilers at work in this neighbourhood at the present time are of this kind; consequently, it may be worth while to go more particularly into the details of the subject in this place, with a view to shew the importance of obtaining a good proportion between the various dimensions of the boiler, and the horse power of the engine it is intended to be applied to, by pointing out the particular evil effects that generally arise where the above proportions are materially departed from.

It must be observed, that the dimensions just given of a twenty horse boiler are occasionally varied in respect of depth, say from 6 to 7½ feet, without making any great difference in the evaporating power, or the consumption of fuel, so long as the extent of bottom surface and quantity of water remains the same. This boiler is also sometimes made with flat sides, instead of being concave outwards; but this alteration has always a deteriorating effect, which appears to arise from the hot air in the side flues not acting so effectually in a lateral direction, as when it is allowed to impinge *upwards*, although the surface against which it acts may be ever so little inclined from the perpendicular. Besides, the flat sides (unless the water is proportionally diminished in depth) cause a waste of fuel in getting up the steam, on account of the greater quantity of water required to be heated. The late Mr. Matthew Murray, of Leeds, was accustomed to make his wagon boilers nearly flat, or "wall" sided, and gave as a reason, that he merely considered the side flues useful as a casing to prevent the dissipation of heat by conduction; but he took the precaution to have a much larger proportion of bottom surface.

USUAL MISMANAGEMENT OF BOILERS.

24. The circumstances which chiefly alter the effective power of a boiler are such as relate to the setting of it up, or the construction of the brick-work: for instance, the seating walls on which the boiler rests are sometimes 9 inches thick, which reduces the area of the bottom surface from 10 or 11 square yards to less than 9; at the same time the fire-grate is reduced perhaps 6 inches on each side, or about 4 square feet, leaving only about three quarters of a square foot per horse power, which is supposed to be the proportion of fire-grate allowed by Boulton and Watt. It is true, that a boiler so constructed and set up, will make sufficient steam to work a good 20 horse engine with moderate economy, but it is always found that if the engine should happen to be temporarily out of order, or overloaded for a short time, so as to require one half as much more steam; such a boiler then requires what is technically called hard firing, and very soon becomes burnt away in that part of the bottom which is immediately over the back part of the fire-grate. Indeed this effect usually results when a boiler is too little for its work, and is in reality what may be always

expected when we endeavour to get steam with a small fire acting with great intensity, rather than a large one at a lower temperature.

25. For the purpose of arriving at a clear elucidation of the causes concerned in the production of this effect, we shall not digress much if we describe the general routine of management that usually follows. It most frequently happens, when a boiler bottom is burnt out as above stated, that the proprietor, instead of causing an investigation into the circumstances, immediately sends for the boiler-maker, or rather boiler-*mender;* the rent is patched up, and the bricklayer replaces his bricks and mortar precisely as before, when, as the same causes continue, of course a similar rupture takes place before another month is over. Again, the same tinkering process is resorted to, and after a few rounds of this kind, when the expense of repairs has pretty nearly amounted to as much as might have purchased a new boiler, to say nothing of the trouble and confusion necessarily attending such jobs in a regular factory, the wearied proprietor at last sends for another boiler-maker, when (after something being said about bad iron, &c.) the boiler is condemned, and a new one ordered to be substituted for it.

To make sure of the new boiler being large enough this time, a thirty, and not unfrequently a forty horse boiler is fixed upon to replace one of twenty horse power. When the new boiler is to be set up, it generally happens that the same want of knowledge is evinced by both boiler-maker and bricklayer, as in the case of the first, but there is a sufficient supply of steam for the work, and, consequently, all parties are satisfied. Although the expenditure of fuel may be much larger than it ought to be, that is seldom found out immediately, or if so, it is perhaps laid to the account of the newness of the brick-work, and in the mean time, many other changes may have occurred to take the blame from the unnecessarily large boiler; for instance, the fireman may have been changed—the coal may have been obtained from a different quarter—some alteration may have again occurred to the engine—the oil may be different—the weather may be colder, or it may be wetter, and the atmospheric pressure low, and, consequently, the draught of the chimney will be worse than usual,—nay, the weather may be too warm where there is a scarcity of condensing water, and, consequently, the vacuum of the engine will be impaired; and in short, where there are so many circumstances to be taken into account, it very rarely happens that the parties immediately interested are able to draw the proper conclusion.

It may be, and indeed it is, very frequently said, that the importance of the thing is not great, provided that a boiler is rather over than under its work, even if the consumption of fuel should be increased by five or ten per cent., and which is certainly not much in a small concern, when set against the convenience of having it in your power at any time of adding six or eight horse power to your engine by putting in a larger cylinder. But if we consider the setting out of new establishments upon the immense scale of many now at work in this district, in which the expense of coal amounts to three or four thousand pounds per annum, a saving of even only five per cent. is not a trifle to be overlooked, to say nothing of the absurdity of the laying out of large capitals upon mere guesswork principles, or at least, in such a manner as to make extensive alterations in the boilers and engines a matter of almost certain expectation before the concern is fairly at work.

26. When the capitalist is about to erect a factory, unless he be a man of sufficiently comprehensive mind, and able readily to apply a general practical knowledge of the various trades of builder, engine-maker, boiler-maker, millwright and machine-maker, as well as that of cotton-spinner, or what-

ever business the factory is designed for, it will be in vain for him to expect any thing like a scientific execution of his plans, although his general design may be ever so judiciously arranged. Two of the above trades are frequently combined in the same party, more especially that of engine and boiler-maker, but it is far from being general, except in those establishments that are very extensive; and in Lancashire, on account of the great increase of the latter business, and partly owing to the increased consumption of boilers used in steam navigation, it is now considered nearly as a separate trade. It is this circumstance, as much perhaps as any other, which has rendered the present investigation of the subject necessary. There is one custom, however, which has a great tendency to prevent improvement in this branch of business, and that is, the prevalent one of contracting for the making of boilers by weight, which is a direct inducement for unprincipled makers to underwork each other, until there is not enough profit left to repay even so little skill as is required to make the most ordinary rough draught on paper of the article wanted.

27. When a manufacturer wishes to give an order for a new boiler, he of course first ascertains the price of iron per hundred weight, and also the rate of wages per hundred weight for making, and he has then nothing else to do but find out some master boiler-maker who will admit of being squeezed down to the minimum of profit, and he may then expect the natural consequences of competition, namely, a much larger boiler than is necessary, besides being a great deal heavier than it ought to be even for that large size; together with other faults that are more serious, but which arise principally from the difficulty of riveting (by mere manual labour) very thick plates of iron so as to be perfectly water-tight, without the use of various means to prevent

leakage, such as a cement composed of red lead and iron borings, or a coating of paint, or coal tar.

28. There is also a very common practice, which it would be inexcusable to pass over without notice when treating on this subject, and that is, the making use of a wash for the purpose of *rusting* the iron in the imperfectly filled rivet-holes and unclosed joints of the plates; by this means a coating of *oxide* can be given to the inside of a new boiler in a few days, sufficient to prevent the leakages until it has been a short time at work, when a little dirt or incrustation comes to assist the rust in forming a more permanent covering. This, when once formed, becomes a regular lining or shield of non-conducting substance between the heating surface of the boiler and the water which is to be heated. Thus it is that the unsuspecting manufacturer comes to be furnished with what he considers at the time a *cheap* boiler.

EFFECTS OF ENLARGING THE FURNACE.

29. Returning to the subject of the unnecessarily thick seating walls, (Art. 24,) a great portion of the brick work is sometimes removed, and the boiler sustained by four, six or eight cast iron blocks or short columns, and with merely a brick in breadth wall to divide the flame bed and furnace from the side flues. This plan is a good one, so long as the brick-work remains tight, for the alteration is always followed by a great increase in the evaporating power of the boiler, as well as a proportional saving in fuel.

30. In effecting this alteration, care however must be taken that the enlargement of the furnace does not injure the draught, otherwise a contrary effect to that expected may be produced; more particularly if the chimney is small so that there is not a surplus draught at command. In such cases it is generally

necessary to diminish by a small amount the space between each grate bar, in order that the total area of the spaces between the bars may not be increased in so great a proportion as the area of the grate itself.

31. With regard to the two last-mentioned effects, namely, an increased evaporating power, and a diminished expenditure of fuel, it must be observed that they ought not to be confounded together, for although they are generally accompanying results of enlarging the furnace, they are traceable to very different causes. The increased evaporating power of the boiler is always found to be in the same ratio as the increased area of the fire-grate; while the saving in fuel seems to bear a certain proportion to the increase in the heating surface *immediately over or very near the fire*, the fire-grate itself remaining the same, or in some cases even diminished. This is an important distinction, as will be farther exemplified when we come to treat of locomotive boilers or boilers with fire-boxes.

32. There is another fact connected with this part of the subject, which must have struck any one who has been at any considerable pains in making observations, and that is, that the heating surface near the fire is so much more effective than those parts of the boiler which are beyond the occasional reach of the flame, as hardly to admit of any comparison; certain it is, that two or three square feet of additional surface over the hottest part of the fire, makes a considerable improvement in the power as well as in the economy of a boiler, while as many square yards of surface added to the contrary end, or that next to the chimney, has scarcely any effect at all, provided that the proportions of the boiler in other respects remain the same. It has been found that when boilers of twenty feet long have been lengthened by

ten feet, the alteration has made hardly any difference in the evaporating power, while the area of the fire-grate remained the same, and the saving of fuel, if any, has only been trifling. Again, we have seen a boiler cut down from one hundred feet in length to fifty without any sensible diminution in its evaporating power, in proportion to the area of its fire-grate. In both these cases, both before and after the alterations, the temperature of the air and smoke escaping into the flues of the chimney was so considerable as to enable it to boil water in an open vessel very rapidly.

Since the publication of the last edition of this work, parties who are strangers to the great extension of steam power in Lancashire during the last twenty years, have ventured to doubt the existence of steam boilers of such a large size as that mentioned in the above paragraph, which makes it now necessary to add, that the instance stated occurred at the extensive paper works of Messrs. Cromptons, at Ringley, five or six years ago; and also that boilers of nearly equal power, and of fifty to sixty feet long, are not uncommon at several of the extensive printing, bleaching or paper works in this county. The boiler in question was a plain cylinder, with hemispherical ends, 104 feet long and 5 feet 3 inches in diameter, and estimated to be about 100 horse power; it contained no inside flue, and had only one furnace, which was placed underneath the bottom near to one end, containing 100 square feet of fire-grate, being 20 feet long and 5 feet wide, and fired sidewise. The impossibility of stoking so large a fire properly was alone the cause of the boiler being altered.

There are also a few instances of very large boilers at factories. One boiler, in particular, has been at work for several months past at a cotton mill in Manchester, which may be mentioned as being probably the largest steam engine boiler in the world; it is a cylinder of 90 feet long and 8 feet in diameter, with a cylindrical flue through its whole length, and if it could be properly fired, may be estimated at about 200 horse power.

33. From what has been stated it will be easily perceived that in many cases where a boiler does not produce a sufficiency of steam, we have only to cut away the side walls of the furnace, and thus by increasing the width of the fire-grate, considerably augment the power of the boiler. Even where there is a manifest insufficiency of heating surface, the simple and inexpensive plan of enlarging the furnace may be carried to the extent of increasing the evaporating power of a boiler to nearly double that which its quantity of heating surface would otherwise warrant, and without any very material increase in the ratio of the fuel consumed to the water evaporated.

34. There can be no doubt that the best proportional area of effective heating surface, to that of fire-grate, is at any rate not more than *nine* to *one*, or a square yard of surface to a square foot of fire, as we have already assumed; but it is not meant to be denied that a ratio of *ten* to one, or even *twelve* to one, which is generally supposed to be the correct proportion, is still more economical in theory, but it is so in *theory* only and not in practice. Indeed, if we follow theory, it may be doubted whether a ratio of a hundred to one, may not be nearer the correct proportion; for it is evident that the hot air or smoke ought not to pass into the chimney, until it is entirely deprived of its power of generating any more steam, or in the language of the chemists, "until it has imparted the whole of its superabundant *caloric* to the water," excepting so much as is sufficient to cause a good draught, and which is generally found to be at about 4 or 500 degrees of Fahrenheit, varying according to the construction of the chimney.

It is evident that there will be a different ratio of heating surface suited to the different qualities of fuel, but we are speaking of the best engine coal used in this district. For the Welsh coal and some others, the heating surface will bear a still smaller ratio; and for coke the least of all.

35. A very eminent lecturer* not long ago, in Manchester, even went so far as to advise that the heated air and smoke ought to be kept in contact with the boiler until reduced to 212 degrees, or to such a temperature as corresponded with steam of the required pressure, and which for a low pressure engine would seldom be much above 220°, this recommendation appears good as a point of theoretical perfection to be aimed at, if it could be done, but it is not practicable. The result of our experience is, that with the ordinary forms of boilers in use, and with the average of engine coal used in this district, there is nothing to be obtained by extending the boiler bottom to a greater length beyond the furnace, than the farthest point to which the flame will occasionally reach when the fire is managed in the ordinary way; and in general, nine square feet of effective heating surface for each horse power, is sufficient to enable us to make such an arrangement of the forms of all the simpler sort of boilers, as will reach far beyond that point. Now when we say that nothing is to be obtained by an extension of the length of the boiler beyond the limit stated, it is meant that the saving would be less than the simple interest of 5 per cent. per annum on the cost of the extra quantity of boiler plate required for the additional surface which such extension would

* The Rev. D. Lardner, LL.D., F.R.S., &c., to whose work on heat, and also that on the steam engine, every engineer, in common with the public generally, must feel greatly indebted. They are useful collections of interesting and important matters on their respective subjects, which are no where else to be found in so small a compass.

render necessary; to say nothing of the additional expense of brick-work required by the larger size of the boiler. The saving of fuel is admitted, but it will cost more than it is worth; and herein engineers may see an example of one of the many cases in which theory not founded upon experiment is at variance with practice: the scientific theorist will not admit the truth of any thing which there is not a reason for, while the practical man will not adopt any plan which has not been proved to answer, whether there is a reason for it or not. Hence it is that they continually disagree, dogmatic theory says he has *made* it so and so by calculation, while practice says he has *found* it different by experience. They are both in the wrong, although it must be acknowledged that after all the only just criterion in such cases must be experiment and observation.

ON BURNING SMOKE.

36. In nothing has the philosophical manufacturer or amateur mechanic been so much at variance with facts and the experience of practical men as on the subject of *smoke burning*. It is perfectly true that the black carbonaceous matter which usually escapes along with the incombustible gases, and which is the only *visible* constituent of what we term smoke, is all so much fuel, and when properly consumed under the boiler is undoubtedly a saving of coal; but it unfortunately happens that the saving is such an inappreciably small quantity, that none who have tried it have been able to calculate its amount, except in certain cases when it has taken the so much dreaded negative form. It is far from my intention to speak disrespectfully of any of those who have proposed to save fuel by burning smoke, for they have generally deceived themselves before they led others astray, as the hundreds of patents, as well as the hundreds of thousands of pounds that have been expended over them amply testify; indeed they deserve no

small share of our gratitude from the opportunities the subject has given of ascertaining by experiment a great number of practical results which we can now make available in other more important improvements.

This subject is introduced here because it is closely allied to the one we have just been considering, namely, that of enlarging the furnaces of boilers; and I speak with the more confidence in this particular, from having had a good deal of practice in directing the application of several of the various methods of smoke-burning which have been tried in this country, since the legislature made it in some measure compulsory. Several boilers are now working in this district which have undergone various improvements under my directions, and with which I had undertaken to *save fuel*, and at the same time *burn the smoke*, and which were in almost every case successful; but mind, the fuel was not saved *by burning the smoke*, but by the adoption of various alterations and arrangements which the previous defective proportions or bad management of the particular boilers admitted.

37. Very few instances occurred where the attempt might be called a signal or total failure; and a failure in smoke burning is usually signal enough. There is a very common answer which enginemen are in the habit of giving to their employers when questioned as to why they allow so much smoke to fly away without burning it; it runs thus,—"Master, if you will only tell me how to catch it and bring it here, I'll be bound to burn it." Now in the year 1829, a gentleman in a neighbouring town* put the idea contained in this joke to the test of experiment, and it arose from the circumstance of his having two steam engines, one situated at the foot of a hill and the other near the top, so that the smoke from the lower engine was carried through

* Joseph Jones, Esq., Walshaw Mills, Oldham.

a tunnel or flue up the side of the hill, which in some measure answered the purpose of a chimney, and escaped by a shaft or stack near the higher engine. Consequently the situation admitted of great facility in arranging a plan for setting the question at rest, as to whether any saving was to be made out of burning the smoke or not; and as it was intended to be a sort of *experimentum crucis*, I willingly engaged to superintend the putting it into practice. Accordingly we had alterations made in the furnaces of the upper engine, in order to admit of the whole or any portion of the smoke from the lower one, without any obstruction to the draught of either. Proper valves and dampers were fixed for the purpose of admitting and regulating any required portion of atmospheric air, in order to supply the necessary quantity of oxygen to the new combustible. And in fact from 30*l.* to 40*l.* was expended in apparatus, so that nothing should be omitted which had any chance of securing the success of the experiment; but it was all of no avail, and the result was as already stated. The smoke to be sure might be said to be *burnt*, for it passed through a very hot furnace, but it certainly was not *consumed* as usually understood, for it always appeared to me to be much blacker at the chimney top after having passed through the furnace, than it did when it was allowed to pass off without going near the fire at all. And as to the saving of fuel by the process it may safely be pronounced *nil*, for unfortunately we were never able to raise sufficient steam with it to keep the engine going for a quarter of an hour together.

38. The circumstances attending the above experiment are stated, because we believe it to be the first of a series of attempts to consume smoke by combustion, according to a principle lately revived by numerous patentees and experimenters in this neighbourhood, although originally suggested and patented by the late Mr. Watt, in 1785. The

great secret of smoke burning, however, is now pretty well known to practical smoke burners, and that is, either to make very little (*or none*) to burn, or otherwise so to dispose of the fuel in the furnace, that smoke of such a quality only is made, as will burn comparatively easily; and in either process the saving in fuel is a point yet unsettled.

In the first case, by keeping a thin fire, and throwing on the coal by a very small quantity at a time, which is most advantageously done by the firing machine, and with a free access of air through the grate, we are assured that no *combustible* gases escape from the furnace; consequently the very small quantity of solid carbon held in suspension (principally by the extricated azote and other *incombustible* gases) is the only portion of the smoke capable of combustion, and to effect which, a most intense heat with a rapid supply of oxygen is necessary, and in a much greater degree than the ordinary economy of a steam boiler requires.

In the other case mentioned, in order to produce smoke that will burn more easily, it is requisite that a large quantity of coal be laid on at a time, and also to have a slow draught, so that nearly the whole of the carbon evolved is combined in the production of carburetted hydrogen gas. In fact, the furnace with a thick fire, may be likened to a gas retort, and the carburetted hydrogen thus distilled forms an explosive compound when mixed with a fresh supply of atmospheric air at the bridge of the furnace. This last is on the principle of Mr. Parkes, whose system of smoke burning came so much into favour some years ago, but which is now nearly extinct, although it is yet a point much debated, whether a thick fire with a slow draught, or a thin fire with a quick one, and its necessary accompaniments a firing machine and a good chimney, is the most economical.

39. The very general adoption by the Lancashire ma-

nufacturers, of Stanley's firing machines, and Walmsley's moving fire-bars, would seem to be decisive of their general economy in preference to any system of firing and stoking by hand; but there are other causes for this preference, quite independent of the question of economy of fuel, some of which have had great influence in the general disuse of Mr. Parkes's system of firing; one of which is, that in the latter system the boilers are required to be considerably larger for the same power, a fatal objection here, but which is more or less applicable to every system of smoke consuming that we are acquainted with. The force of this objection will be felt at once by those who are acquainted with the practice of the great majority of the Lancashire cotton spinners, which is that of using their steam engines as some people do post-horses, by making them do as much work as ever they can, short of breaking down. The same remark is also in some degree applicable to the Liverpool steam vessels; they are made to go at their utmost speed, in order that as much work may be got out of them as possible, and in as short a time; although, owing to their being generally the property of Joint Stock Companies, they have, as in the case of most monopolies, not as yet been sufficiently subjected to the stimulus of competition and individual enterprise.

40. The general facts above mentioned are so well known to every experienced fireman and operative engineer, that the saying has almost passed into a proverb with them, absurd as the connection may appear, that "*it requires plenty of boiler room to burn smoke;*" and we know that many of them consider it as easy to drive a 30 horse engine with a 20 horse boiler, if fired upon Stanley's plan; as it is to drive a 20 horse engine with a 30 horse boiler, upon the principle of Parkes. The observations of this class of men are frequently more worthy of

regard than inventors of new plans are generally disposed to pay to them. More especially if we consider that this "instinct of ignorance," as it has been called, enables them to manage all the various complicated arrangements of the fires, engines, and boilers of that wonder of the present age, the "Ocean Steamer," in a manner that we are afraid will not be much improved upon, for a few years to come, by all the engineering classes of our new universities. At any rate, if a little more attention is paid in future to this "instinct," or tact, by some of the marine managers and other supernumeraries of more than one or two of our extensive Steam Navigation Companies, we may be spared the mortification of hearing of such unfortunate attempts in *smoke burning*, as that which is said to have caused the untoward return of the "Liverpool" Steamer to Cork, when on her first voyage out to America.

41. Soon after the unsuccessful experiment of Mr. Jones, already detailed, (Art. 37,) Mr. Horrocks, of Stockport, the well known improver of the power loom, &c., made an ingenious attempt to bring Mr. Watt's principle to bear, and although only partially successful, it forms one great step towards its ultimate accomplishment. Instead of taking the smoke of one fire over the top of another, he caused it to return over the same fire from which it was evolved. This he contrived by means of a most ingenious adaptation of the Centrifugal Fan, or rotatory blowing apparatus. It was worked by the engine at the rate of about 1,500 revolutions per minute, and so arranged that the smoke was drawn from the flue at the further end of the boiler, to the front, whence it was propelled down upon the hottest part of the fire, where its combustion was effected, although imperfectly.

About the same time that Mr. Horrocks was carrying on these experiments, fans were used by Messrs. Braithwaite and Ericson, and others, both for locomotive engines and steam boats. Fans have been also applied by many, both before and since that period, for the purpose of obtaining an artificial blast or draught for the furnaces of steam engines, according as the propelling or the exhausting powers of the fan were employed, but we believe none of them ever employed it for the purpose of returning the smoke into the furnace again. To Mr. Horrocks, perhaps, is also due the merit of first employing both the exhausting and propelling action of the rotatory fan at the same time and in the same process, this double action being carried on in a furnace almost entirely inclosed from the external air.

42. The next attempt to follow up this principle of burning smoke, has been very recently made by Mr. David Cheetham, Jun., of Stayley Bridge; but as at the time of writing this, the specification of his patent has not yet been published, a brief notice of it will suffice here.

As in the Stockport experiments, Mr. Cheetham also employs a fan, and nearly in the same manner; but instead of passing the smoke over the top of the fire as was done by Mr. Horrocks, and also by Mr. Jones, of Oldham, as before stated, (Art. 37,) he sends it into the ash-pit, (which is inclosed,) whence it is by the joint propelling and exhausting action of the fan forced to pass through the fire-grate itself; by which means the flame and hot air in the furnace is propelled with great velocity directly up against the boiler bottom, a circumstance which sufficiently accounts for a considerable portion of the economy of the process.

But there is also another peculiarity which distinguishes this invention from that of Mr. Horrocks, which is, that the small quantity of atmospheric air necessary to supply oxygen to the furnace, is admitted to the fan by an adjustable aperture, and allowed to become heated by intermixture with the smoke and hot air, as they are returned to the ash-pit. Thus the process acquires many of the well known advantages belonging to the hot air blast, as used in metallurgic operations. The saving in fuel is stated by the patentee to be about 20 to 30 per cent., and we have had opportunities of ascertaining, that in some cases this statement is not overrated; but how much of this saving is to be ascribed to the improved draught, and the peculiar application of the hot air blast, or whether any portion of it is derived from the actual combustion of the smoke, there have as yet been no direct experiments to prove.

43. In the course of our practice in saving fuel and burning smoke, we always found that nothing tended so much to the accomplishment of both these objects as enlarging the furnace and flame bed, and where the draught of the chimney was good, also enlarging the fire-grate. In adopting this last alteration, it was always found that the maximum effect was produced when the area of the fire-grate was increased in a somewhat greater ratio than the effective heating surface was diminished:—that is, when a certain effect is to be produced, say, for example, an evaporating power equal to the supply of a twenty horse engine, which, we have seen, requires twenty square yards of effective heating surface, but from malconstruction of the boiler or other circumstances we have only eighteen yards, then the furnace will require to have a fire-grate of a *little more* than twenty-two square feet in area; or if the heating surface be only sixteen yards, then the fire-grate will be required to be *more than twenty-four*, in fact about twenty-five square feet.

44. The best way is to make the area of the fire-grate such, that the number of horses power of the boiler, may be a geometrical mean between that area, expressed in square feet, and the area of the effective heating surface expressed

in square yards. This proportion gives a convenient rule for ready application in practice, and although empyrical, it has never been found to fail in producing the wished for result, provided that the boilers have been in other respects suitable, and it has been tried in several hundred cases. It is therefore inserted here symbolically, along with other formulæ derived from it for future reference, and in order that it may meet with more extended application in other parts of the kingdom. Should it require any modification to adapt it to varieties of fuel or other circumstances, it will from its simplicity easily admit of such alteration as future experience may point out.

FORMULÆ FOR FINDING THE HORSE POWER, THE AREA OF THE FIRE-GRATE, AND THE AREA OF THE EFFECTIVE HEATING SURFACE; USEFUL IN ALTERING OR RESETTING OLD BOILERS.

45. Let S represent the number of square yards of effective heating surface; F, the area of the fire-grate in square feet; and P, the horse power of the boiler; then will the following simple formulæ express all the relations of those quantities, sufficiently convenient to be inscribed in a corner of a two foot rule.

1. Horse power .... $= P = \sqrt{SF}$.
2. Fire-grate .... $= F = P^2 \div S$.
3. Heating surface .... $= S = P^2 \div F$.

To make these rules for boilers as extensively useful as possible they are in words as follows:—

46. To find the horse power.

Rule.—Multiply the area of the fire-grate in *square feet*, by the area of the *effective* heating surface in *square yards*, and the square root of the product is the horse power of the boiler; provided only that there is not less than one square foot of fire-grate for each horse power, and about one cubic yard of capacity or boiler room for the same.

47. As examples of the arithmetical operations of this and the following rules may be useful to a large class of workmen, they are also added.

EXAMPLE 1.—Suppose a boiler to have 16 square yards of effective heating surface, and a fire-grate of 5 feet square, or 25 square feet in area; required the horse power.

Area of fire-grate ... 25 square feet.
Ditto of surface...... 16 square yards.

```
                 ----
                 150
                 25
                 ----
Product......400 (20 sq. root, or horse power req.
             400
             ----
             . . .
```

EXAMPLE 2.—Suppose a boiler to have 18 square yards of surface and a fire-grate of 5 feet long and 4 feet 6 inches wide; required, the horse power.

Area of fire-grate ($5 \times 4\frac{1}{2}$) = 22·5 square feet.
Ditto of surface............... 18 square yards.

```
             ------
             1800
             225
             ------              [power req.
             405·0 (20·12=sq. root, or horse
             4
             ------
        401) 0500
              401
              ------
        4022) 9900
              8044
              ------
```

48. How to find the area of the fire-grate when the surface, and horse power are given:—

Rule.—Divide the square of the horse power, by the square yards of effective heating surface, and the quotient is the area of the fire-grate in square feet.

The following rule is also the converse of the last.

49. To find the area of effective heating surface, when that of the fire-grate and the horse power are given:—

Rule.—Divide the square of the horse power by the square feet of fire-grate, and the quotient is the area of effective heating surface in square yards.

Example 3.—Suppose a 20 horse boiler has only 16 square yards of surface; required, the area of the fire-grate.

Horse power 20
20
―――
Divide by surface 16)400 (25 quot. or area of the fire-grate, [in sq. feet.
32
―――
80
80
―――

Example 4.—Suppose a boiler has a fire-place of 4 feet 5¼ inches wide, with fire-bars of 5 feet long; required, the area of effective heating surface to enable the boiler to drive a twenty horse engine.

Horse power 20
20

[of surface required.
Divide by area of fire-grate 5 × 4·44 ...... } = 22·22) 400·00 (18 quot. or sq. yards
2222

17780
17776

APPLICATION OF THE RULES AND FORMULÆ FOR DIFFERENT QUALITIES OF COAL.

50. It is necessary to bear in mind that the above formulæ are only true, when F is at least equal to P, at any rate it is so in this district, and in others, where the quality of the coal is different, the value of F will always bear some fixed relation to P, which can be easily ascertained by a few experiments.

Let us suppose, for example, that in some situations the coal obtained is of such superior quality, that when it is used, *three* square feet area of fire-grate is found to have as great a heating power, as *four* square feet of grate has, when the coal is used from which the data is obtained, or in other words with such coal, that $\frac{3}{4}$ of a square foot area of fire-grate is sufficient for one horse power; then, if the other conditions of the boiler remain the same as before, we have only to take the reciprocal of $\frac{3}{4}$, namely, $\frac{4}{3}$ or its decimal equivalent 1·333, and use it as a coefficient to F in the expression for the horse power, which will then be—

$$P = \sqrt{S \times 1{\cdot}333\, F} = \sqrt{1{\cdot}333\, SF}.$$

The boiler which is the subject of the first example to Article 47, is by this formula equal to $\sqrt{1{\cdot}333 \times 25 \times 16}$ $= 23{\cdot}09$ horse power.

Here the proportion of effective heating surface compared to the area of fire-grate may be expressed by 9 : ·75 or as 12 to 1.

51. But should the same proportion of surface to fire-grate be also to be observed as before, namely, that of 9 to 1; then we must use the same coefficient to S as to F, and the equation becomes—

$$P = \sqrt{1{\cdot}333^2 \, SF}, \text{ or } P = \sqrt{1{\cdot}7833 \, SF}.$$

According to this, the above boiler (*see* Art. 50.) will be equal to $\sqrt{1{\cdot}7833 \times 25 \times 16} = 26{\cdot}65$ horse power.

52. Again, suppose that $1\frac{1}{4}$ square feet should in any case be thought necessary for the area of fire-grate for each horse power, (and it is so considered by some, who use the small refuse coal or sleck,) and also that $1\frac{1}{2}$ square yards of effective heating surface per horse power might not be thought too much, (about 18 square feet of total surface which, in fact, is the proportion used in several of the large bleach works in Lancashire,) then the coefficient

of F will be $\frac{1}{1{\cdot}25} = {\cdot}8$, and that of S $\frac{1}{1{\cdot}5} = {\cdot}666$,

and the formula for the horse power would be

$$P = \sqrt{{\cdot}666 \, S \times {\cdot}8 \, F}, \text{ or } = \sqrt{.533 \, SF}.$$

This last supposed case is a junction of two extremes, which is hardly possible ever to occur in this country, and certainly never can be necessary. It is only introduced here to shew how to adapt the formula to different varieties of coal, and in this case it is adapted to the worst possible kind. The coefficient of S F may be taken generally to represent the value of coal as to its power of generating steam, and which is never likely to be less than ·8 and perhaps never less than ·9.

53. In regard to the other limit to the value of the coefficient of S F, namely, that for the best coal, it is more difficult to be assigned, because various methods of increasing the effect of fuel, by building larger chimneys, and by improved modes of firing, are continually being brought into practice; and if in particular we could discover any means of further improving the draught of furnaces at a small expense, so as to enable us to use the Anthracite or Stone Coal, of which there are such vast quantities in Wales and in Ireland, there is no doubt but the value of its coefficient would be expressed by a number fully equal to that stated in Article 51, (namely, 1·7833,) which would be a most important thing for steam navigation, as it would increase the power of the boilers by one-half, and effectually do away with the nuisance of smoke.

THE SLIDE RULE.

54. Our formula for the horse power of boilers admits of a very convenient exhibition on the common carpenter's slide rule, as follows:—

Slide inverted	A	Horse power = P	Sq. feet area of fire-grate = F.
	Ↄ	Horse power = P	Sq. yds. of heating surface = S.

EXAMPLE 1.—Suppose, for example, that S = 18 square yards, and F = 22·2 feet, then invert the slide and place 18 on C, against 22·2 on A, and looking to the left hand, the first two divisions of the same value that coincide with each other (and which are those of 20) represent the horse power, as in the example below:—

Slide inverted	A	P=20	F=22·2 Square feet.
	Ɔ	P=20	S=18 Square yards.

EXAMPLE 2.—Again, suppose that the same number of horse power is required, but that the effective heating surface has been reduced from 18 square yards to 16, then opposite to 16 on C will be found 25 on A for the area of the fire-grate, as follows:—

Slide inverted	A	20	22·2	25 Square feet.
	Ɔ	20	18	16 Square yards.

EXAMPLE 3.—Suppose that a boiler is intended to drive a thirty horse engine, but it has only 25 square yards of surface; the area of the fire-grate is required.

Place 30 on Ɔ, against 30 on A, then against 25 yards of surface on Ɔ, you will find the answer to be nearly 36 square feet on A for the area of the grate, as below:—

Slide inverted	A	30 horse power	Fire-grates	31, 34, 36, 39.
	Ɔ	30 horse power	Surfaces	29, 26½, 25, 23.

And in like manner against any number expressing the square yards of effective heating surface on C, you will find the number of square feet area of fire-grate most suitable to it on A. In short, the inverted line C represents a table of 30 horse boilers with various quantities of surface; and the line A represents a table of areas of fire-grates corresponding to it. The rule, when thus set, exhibits at a glance the various ways in which a 30 horse boiler may be set up.

55. It will be seen that any one of the three data respecting boilers may thus be found, when the other two are given, by any intelligent workman, without the use of a single

figure; and it is for his use only that these examples are given so much at length.

Example 4.—The same results are still more conveniently obtained by using Routledge's or the Soho slide rule, on which all the four lines may be used without inverting the slide, as follows:—

A	Area of Fire-grate 25 square feet.	
B	Constant number 100 or gauge point.	
C		Surface 16 square yards.
D		Answer 20 horse power.

CHAPTER II.

ON THE CAPACITY OF THE STEAM CHAMBER AND BOILER GENERALLY, AND ON THE EFFECT WHEN TOO SMALL, WITH RULES FOR THEIR ALTERATION AND IMPROVEMENT.

56. The proper capacity for the steam chamber or steam chest, has been much less considered by engineers than proportion of heating surface. The reason why it has appeared to some of them of little consequence, shows us, at least, one case in which theoretical and practical men do occasionally agree; it being principally owing to some of the latter having about as much theory, and no more than is just sufficient to lead them astray, and thereby become blind guides to those who have no practical knowledge at all.

57. If instead of the steam chamber we have a close box or vessel, containing a permanently elastic gas, or even steam itself separated from water and allowing its temperature to remain the same, and supposing that a communication is made, by means of a cock or valve, with a second vessel of the same capacity as the first and quite empty; then, as soon as the second vessel becomes filled with the expanded fluid, it is evident that the latter, by occupying double the space, will be reduced in elastic force or pressure exactly one half, the resulting pressure being always inversely as the expansion.

Now if we further suppose the first vessel to be constantly receiving a uniform supply of steam, or other elastic fluid, we can obtain a rule for making the two vessels in just such proportion to each other, as will keep any variation in the elastic force of the steam, during any required short periods of time necessary for successively shutting and opening the valve of communication, within any given limits.

We need not, however, follow Tredgold's example by making the calculation, because, although it has some similarity, it is far from being a parallel case to that of a steam engine boiler and cylinder. In the latter case, there is nothing like an uniformity of supply in the boiler; for although the action of the fire may be supposed to be uniform, yet, by far the greatest portion of the steam is very rapidly generated during the first half of each stroke of the piston, and at which time only, ebullition, properly so called, takes place, but which usually ceases immediately after the piston passes the point of its greatest velocity, or when the crank is at right angles. This effect can be distinctly shown in a glass boiler, and the great difference in the quantities of steam produced, in the same time, by water *in a boiling state*, and *when not boiling*, although at the same temperature, it is unnecessary to insist on.

58. Returning to the assumed case of the two vessels, and supposing that the first (which may represent the steam chamber of a boiler) is regularly supplied with steam by a constantly uniform evaporation of the water; then, the pressure of the steam must evidently always retain the greatest degree of uniformity, when the flow of the latter through the channel of communication with the second vessel (which vessel may represent the cylinder) is interrupted for the shortest possible period of time; consequently, under such circumstances, a smaller capacity of steam chamber will be sufficient to render any variation of pressure inconsiderable, than if those interruptions were to occupy a greater portion of time.

This is, indeed, precisely what follows from the erroneous theory of Tredgold, founded as it is upon the mistaken assumption of an equability in the generation of steam, as may be seen by a reference to his work, (Articles 210, &c.,) where by means of it he endeavours to show that an engine working expansively requires a larger boiler than when acting at full pressure. The impossibility of such a conclusion being the true one, ought to have struck any one in the least practically acquainted with the subject; and is only equalled in absurdity by a statement in the same work, quoted from Prony's Architecture Hydraulique, to the effect, that it was one of the advantages of a double powered engine, that it required a smaller boiler than a single acting one, which in fact must have arisen from the same false premises and the same mode of reasoning.

Thus, according to Tredgold's theory, all those engines whose valves are closed for the shortest portion of time between the strokes, other things remaining the same, require the least capacity of steam chamber; but the reverse of this is the fact. For it is proverbially well known, that the old fashioned hand gear or tappet valve engine, invariably requires more steam room in the boiler, than the modern or slide valve engine, in which the valves are worked by an eccentric, the action of opening and shutting the valves not being so sudden as in the former.

59. The steam in a boiler, of course, continues to accumulate, although slowly, during the time that the induction valve is quite closed; but as soon as the momentum of the fly wheel carries the crank over the centre and opens the valve, the surface of the water in the boiler is, with the commencement of each stroke, simultaneously relieved from a portion of the pressure of the steam, and the water immediately commences boiling, let its temperature be what it may.

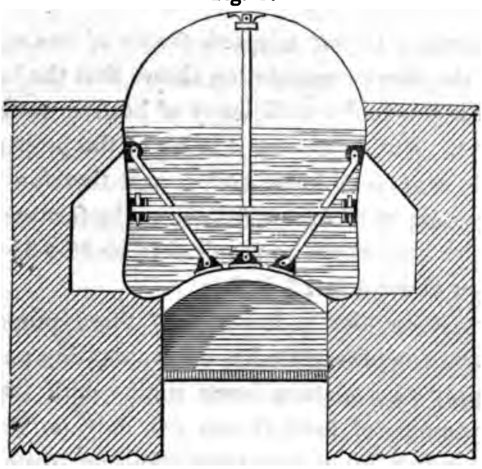
A very demonstrative way of illustrating this intermittent action of the water of a steam engine boiler, is to adapt a test tube with a small portion of the bottom cut off, to the neck of a common Florence flask containing boiling water and placed over a lamp or gas light; then, by using a cork by way of piston, and the test tube as a cylinder, the phenomenon may be produced in miniature exactly as it occurs with the steam engine itself, and the experiment may be made visible to a large assembly. It is, however, necessary to recommend caution in experiments with glass boilers, and it may be useful to state, that, when the water is at a boiling temperature, if the cork be totally and *suddenly* withdrawn, the whole of the hot water will be projected from the flask or discharged upwards with considerable force.

60. Now it will be at once perceived by those who may repeat this experiment, that the manner in which steam is produced in the boiler of a steam engine *at work*, is partly by a *distillatory process* during the times that the valves are closed, or, properly speaking, by *evaporation*, and which is dependent upon the extent or superficial area of the evaporating, or water surface, as well as upon the heating surface; but, of course, the steam is principally produced during the short periods of ebullition, its production in the latter case being termed by chemists *vaporisation*, which serves to mark a proper distinction; but we shall generally use the more common term *evaporation*, to express the compound process we have been describing.

61. The best way perhaps that we can examine and determine the proper capacity of boilers in relation to their horse power, will be to take an example, by which means we can at the same time show our method of treating any similar case in actual practice.

In pursuance of this object, we shall therefore make an application of the principles evolved in the last chapter to the case of what may be considered a badly proportioned wagon-shaped boiler, although of the same horizontal dimensions as the last, (Art. 19,) and therefore usually considered of twenty horse power. Its dimensions are 20 feet long, 5 feet wide, and 6 feet deep, (see Fig. 3.) The furnace is

Fig. 3.



$3\frac{1}{2}$ feet wide, and the boiler bottom being arched 8 inches, it is about 3·75 feet broad, (measuring by the curved surface,) which multiplied by the length, gives 75 square feet of bottom surface. The water being about the same depth as in Figure 2, (Art. 21,) or about $3\frac{1}{2}$ feet, and the vertical height of the heating surface exposed in the side flues 3 feet, one half of this being effective, there is $1·5 \times 40 = 60$ square feet in area of effective heating surface in the sides. The effective heating surface of the ends may be taken to be the same as in Figure 2, for although less in depth it is made up for by greater width on account of the nearly flat sides, or say 12 square feet. The total effective heating surface will then stand as follows:—

		Sq. Ft.		Sq. Yds.
Boiler Bottom		75	=	8·333
Vertical Surface	Sides=60, Ends=12	= 72	=	8
Total			=	16·333

62. According to our adopted theory of one square yard per horse, the above computation shows that the boiler is $3\frac{2}{3}$ square yards short of a sufficiency of heating surface for 20 horse power. But supposing it to be of the proper capacity it would be a good 16 horse boiler, and therefore ought to have a fire-grate of 16 square feet, or as the furnace is $3\frac{1}{2}$ feet wide, the fire bars would be required to be $16 \div 3\frac{1}{2} = 4·57$ ft. in length, or about 4 feet 7 inches.

Now we know that a boiler with these proportions of heating surface and fire-grate has an evaporating power equal to the supply of a sixteen horse engine with the greatest possible economy of fuel; it will not only do this, but it possesses a capability of supplying sufficient steam for such an engine when loaded to one-half more than its nominal horse power, as well as to work with moderate economy when only half loaded; or in other words, a good sixteen horse boiler is capable of working from eight to twenty-four horse power, with something like a proportional expenditure of fuel for the water boiled away; increasing of course in a trifling degree, as the demand for steam rises above, or falls below, the medium point of sixteen horse power, that being supposed to be fixed as the *maximum of profitable effect* after a consideration of all the circumstances of expense of fuel, original cost of boiler, tear and wear, and attendance.

63. There are few subjects connected with the economy of the steam engine on which such erroneous opinions have been held as on that of steam room. Mr. Millington was of

opinion that room for 5 or 6 times the quantity of steam used at each stroke was sufficient, while Dr. Young states that *ten* times the quantity is required; — Mr. Tredgold's calculation, which we have already shown to be based upon a false assumption, purports to prove that a steam chamber sufficient to hold 8 times the quantity used at each stroke, is of the proper capacity for a double acting engine working at full pressure*. In order to compare this with the proportions in general use, we shall assume that the cylinder of a 20 horse engine is nearly 2 feet in diameter, or 4 *circular* feet in area, or in round numbers, say about 3 *square* feet, which will give 12 or 15 cubic feet for the contents of the cylinder, according as the length of the stroke is 4 or 5 feet; but suppose we take the medium, 13½ cubic feet, or half a cubic yard, as the average consumption of steam for each stroke of a 20 horse engine, and multiply it by 8, we shall have 4 cubic yards only, which is at most not more than half as much as it ought to be, as every operative engineer well knows.

CAUSE AND EFFECTS OF PRIMING.

64. If a boiler were only required to generate a certain quantity of steam, and that always at an uniform rate, it would only be necessary to supply it uniformly with water, and by applying a regular heat, the desired result would be attained; but the case is very different to this in practice. From the necessarily intermittent action of the valves of all steam engines, the supply of steam being momentarily cut off at each stroke, as well as for a considerable period during each stroke in those engines that work expansively, the effect is to throw the water of the boiler into an undulatory motion, as may at any time be perceived by observing its effect in

* Tredgold on the Steam Engine, Weale's Edition, Art. 216.

the glass tube of the Water Gauge* now so generally attached to boilers.

65. This undulatory action of which we speak, is apparently independent of, or at least in addition to, the intermittent state of alternate ebullition and repose before described (Art. 57). At any rate, from one of these conditions, or from both combined, it is certain that the agitation of the water occasionally becomes so violent as to cause the latter to follow the steam into the cylinder, and when in too great a quantity to escape through the steam port in the return stroke, it infallibly breaks down the engine.

We speak of the effect thus positively as regards factory engines, because they are not, and cannot be expected to be, calculated to withstand a sudden blow, and such it is in reality. For if the water primes into the cylinder in sufficient quantity in the down stroke, it must remain on the top of the piston until it strikes against the cylinder cover in the up stroke, with more or less violence according to the quantity. From the incompressibility of water, of course the effect is the same as if a piece of iron of equal thickness to the depth of water was suddenly inserted in its place. The tremendous effect sometimes produced when a large engine of 80 or 100 horse power breaks down from this cause is a matter of notoriety in Manchester; for as the vacant space left at the top of the cylinder is generally of no greater depth in large than in small engines, the intruding body of water strikes

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* The *Glass Tube Water Gauge* is an appendage to boilers of so much use in testing the evaporating powers of different boilers, and in ascertaining the value of different kinds of fuel, or the merits of the various modes of firing, that it is a matter of astonishment how it is overlooked by any one; moreover, it is so well calculated to prevent accidents from a deficiency of water, that it cannot be too strongly recommended to all owners of high pressure engines.

the cylinder cover with a proportionally greater force. Generally the accident does not end with merely straining or breaking the crank pin, as is frequently the extent of the injury in small engines; but the momentum of the beam is then added to that of the fly wheel, and their combined force is exerted directly in splitting the cylinder, or tearing off the cylinder cover, thence effectually demolishing all the rods and gearing, in fact the main beam itself also sometimes gives way, leaving almost nothing whole except the fly wheel.

66. In analyzing the various causes concerned in the production of the effects above described, we must not overlook the fact that the tendency of the water to rise into the cylinder is always considerably promoted by the very usual situation of the steam or induction pipe at the back end of the boiler; this seems to arise partly from the constant circulation of the water, which causes a current at the surface, to set in the direction of the length of the boiler from the front end to the back.

This circulation of the water in a steam engine boiler, of course, takes place in *all* boilers, with a certain velocity depending upon the ratio that the intensity of the heat in the furnace bears to the quantity of water to be kept heated; and it is entirely independent of the other two causes before stated (Art. 57—64), but it is most probable that all three are combined in producing *waves* which take their rise over the fire and gradually increase in height as they pass towards the back part of the boiler; for it is a fact, although not generally known, even to workmen, that the water line or mark which is left by the surface of the water on the inside of the boiler is *not level*, but higher at the back end than the front, modified in some degree by the situation of the steam pipe.

67. The peculiar tendency of the water in a steam engine

boiler, to rise into the cylinder, of which we have been treating, is well known to all experienced operative engineers, under the name of "*priming*," "flushing," "pumping," and other similar terms, but it has not been much adverted to by theoretical writers, nor is it yet looked to by steam engine and boiler-makers with that attention which its importance deserves, although it is well known to most of them to be the principal if not the only thing which renders a large steam chamber necessary.

It is remarkable that when the inside of a boiler is examined immediately after the engine has primed much, marks are frequently found running in a slanting direction up the sides of the steam chamber towards the steam pipe, in nearly a direct line leading from that part of the surface of the water which is immediately over the hottest part of the furnace, just as if a partial explosion (if we may so call it) of the water had taken place in that part of the boiler and spent its main force in the direction stated. When there is any considerable quantity of mud or clay in the boiler, the marks indicating the direction of this explosion or *flushing* are particularly legible; and the effects of it, we have had many opportunities of observing in its forcible removal of heavy articles which had been placed in boilers for the purpose of preventing, if possible, the priming of the engine.

68. That *waves* are generated within the boiler when an engine is liable to prime, is a singular but well ascertained fact, as is shown by the frequent great and sudden depressions of the float at such times; especially if the latter happens to be placed at the contrary end of the boiler to that where the steam pipe is fixed. In watching the rapidly successive alternate elevations and depressions of the indicator buoy or float of a boiler in this condition, the tendency to prime may frequently be observed to recur periodically after intervals of a certain number of strokes, provided that

the state of the fire and the load on the engine continue perfectly uniform.

Since the publication of Mr. J. Scott Russell's curious researches on the generation of waves in canals, it has occurred to us that his theory might possibly be applied to the illustration of the above singular phenomenon; and that if so, it will no doubt be found that the depth and form of the water chamber will considerably influence the law which seems to govern the periodical recurrence of this flushing of the water in the boiler. Those who have leisure and inclination to pursue this part of our subject will find it an interesting field of inquiry, and far from being one of mere barren curiosity only, inasmuch as a few well directed experiments may lead to results calculated to unravel some of the still mysterious causes connected with the explosions of steam boilers; than which, no subject is more deserving of the aid of the funds of the British Association for the advancement of Science, on account of the immense importance to the interests of humanity which it involves; and we know of no one half so well calculated both by talent and experience to elucidate that very perplexing and difficult subject than the gentleman above mentioned.

Although digressing farther than was intended, it may, in order to point out the intimate connexion of the two subjects alluded to, be just stated, that, we have known an instance of a very large safety valve (5 to 6 inches diameter) belonging to a high pressure engine that was liable to prime, which would always, on being suddenly opened, discharge nothing but water, (although the latter had not previously been higher than usual,) to the great risk of the boiler becoming short of water and thereby creating an explosion; a fact which shows the inutility of very large safety valves, instead of two or three small ones of the same united area.

69. Although there are many boilers working with Tred-

gold's proportion of steam room, and even with a much smaller proportion, all that we have been able to meet with belong to high pressure or non-condensing engines, or those in which the steam is very much *throttled* or *wire-drawn*; that is, the pressure is invariably a great deal higher in the boiler than in the cylinder, and in some cases nearly double, as the application of the Indicator* has invariably shown. Hence the uniform failure of all attempts to introduce high pressure engines for working the cotton mills in Lancashire, where examples of the low pressure, condensing, or Boulton and Watt engines, are so numerous as to be a ready test of their comparative economy.

From this cause mainly, we have the tampering with the safety valves, and, consequently, accidents continually occurring where high pressure engines are in use. In low pressure boilers, the method of meeting the difficulty of too small a steam chamber, by raising the pressure of the steam, is not practicable to any thing like the same extent, on account of the usual method of feeding the boiler with water by means of the ordinary feed pipe, which boils over when the steam is too high; but where it can be done at all it generally is. With marine boilers, which are supplied direct from the force pump, in the same manner as those of high pressure engines, it is practised to a considerable extent, and is in the highest degree reprehensible, considering the immense destruction of human life that has sometimes taken place by the bursting of the boilers of steam packets.

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* The *Steam Engine Indicator*, as improved and rendered extremely portable by Mr. Mc. Naught, of Glasgow, is now well known in Lancashire; and it is really of so much use to the steam engine proprietor in enabling him to detect the effect of any alterations in the engine, as well as a good approximation to ascertaining the comparative load on engines doing a similar kind of work, that it is only surprising not to find it a permanent appendage to all engines.

PRIMING OF LOCOMOTIVES.

70. It will not, perhaps, be thought that we are dilating too much on this part of the subject, when it is considered what immense sums of money have been expended in running after that *ignis fatuus* steam locomotion on common roads, and ending after all, as has been observed by some one, in bringing us to the humiliating conclusion, that *a sixteen horse power engine will not propel a four horse coach.* Now the priming or the flushing of the boilers, which are necessarily of very small dimensions, is acknowledged on all hands to be the principal difficulty that the various projectors have had to encounter; consequently, there arises the necessity of using steam of two or three hundred pounds per square inch, as appeared by the evidence of Mr. Gurney and others, before the parliamentary committees a few years ago.

It must not, however, be taken for granted that we assent to the first of the above conclusions as containing any thing in the least discouraging to any intelligent projector of steam carriages. For who that really deserves to succeed ever expected that less than a sixteen horse engine will be required to drag a four horse coach upon ordinary turnpike roads, when probably one half of the power of the engine is required to propel itself. The only difficulty as to the engine, is to have sufficient power in the smallest possible space; to effect which, there can be no doubt that the reciprocating principle, with all its rods, guides, cranks, and crooked contrivances must be entirely thrown overboard, and a simple and effective rotary engine substituted. It is however well known, that, amongst all the difficulties steam carriage makers have had to contend with, the boiler has always been the grand rub. That being, as it is termed by the eccentric Col. Maceroni, the very "soul" of a steam carriage, and as it is, indeed, of any other sort of steam engine.

RAILWAY LOCOMOTIVES.

71. Although the steam chambers of the boilers of railway locomotives are not so confined as those just mentioned, yet we venture to affirm, from a general knowledge of the working of the travelling engine upon railways, from its first introduction into the county of Durham in 1815, and a pretty close attention to the numerous alterations and improvements attempted on the Liverpool and Manchester railway, from its opening up to the present period, that the want of sufficient steam room has been the cause of some of the greatest difficulties that railway engineers have yet had to contend with, however unwilling they generally are to admit the fact. How far increasing the gauge of the railway, as is now being done by Mr. Brunel on the Great Western line, will tend to lessen the enormous expense of railway travelling, by admitting the possibility of using larger boilers as well as larger wheels, remains to be seen.

It is a fact of the very utmost importance, and deserves the attention of those interested in railway speculations, that the very large item of expenditure in the reports of the Liverpool and Manchester Company, under the head of locomotive power account, varying from 30 to 40,000*l.* per annum, is, in part, the result of want of sufficient boiler room. In saying this, it is not meant that larger boilers than those at present in use by that company are at all practicable on their line of railway; and much less is it intended to cast the least reflection on any part of the direction, for there has been no lack of zeal in every one concerned in the management, to adopt every possible expedient that promised any chance of abatement under this head of disbursements; it is only mentioned to show the necessity of railway directors, generally, attending more to this point. Science has, as yet, done little or nothing for them; indeed the common fault of railway directors is too great a tendency to adopt the suggestions of mere scientific gentlemen, or the schemes of amateur engineers, because their ideas happen to be clothed in a scientific dress, in preference to plain, practical, and inexpensive improvements of a less ostentatious character.

72. The numerous improvements of the ingenious Treasurer * of the Liverpool and Manchester Company, apparently with a view to avoid the alternative of very large boilers and a reduced speed, and the many curious contrivances adopted from time to time to prevent the priming of the boilers, are proofs that those who have much experience in this matter, consider that in using larger boilers the remedy would be as bad as the evil it is proposed to cure; it is, therefore, now generally admitted that the profitable application of steam to *rapid* railway travelling, is yet surrounded with peculiar difficulties, all of which tend to the conclusion, that although the steam-engine is an agent of almost unlimited capabilities, still it has, as yet, resisted all attempts to confine it as it were in a nut-shell.

If the boilers are made larger and heavier, the destruction of the rails will be greater, besides the danger arising from the increased momentum of the engine in case of accident; on the other hand, if we work with smaller boilers we must have a higher pressure of steam, and then there is the greater destruction of the grate-bars and fire boxes, by the necessarily increased temperature of the furnace, which must render journeys of much greater length than thirty or forty miles with the same engine to be very uncertain and precarious,

* H. Booth, Esq., of Liverpool, the inventor of the present form of locomotive boiler with numerous tubular flues, whose unremitting perseverance, combined with the united talent of the various able engineers and mechanics of the establishment, has rendered the locomotive engine, *as adapted to their own line* and their present arrangements, as to speed and passenger traffic, perhaps incapable of further improvement.

besides the danger and delay attending the continual giving way of the tubes. Again, if we attempt to use the steam at a moderate pressure, although fully equivalent to a reasonable speed, there is the constant liability of the water to prime over into the cylinders, from whence it is forced, by successive blows of the pistons, through the funnel of the chimney, to the great detriment of the whole of the machinery, more particularly of the cranked axles, which, on this account, require to be of such enormous strength; in fact, when the engine primes, the piston is acting for some time like the ram of a powerful force pump or water engine, and the resulting effect must depend upon the acquired momentum or velocity of the engine at the time, and the strength of the parts. Any one may observe the effects of a locomotive engine priming, in a fine shower of spray from the top of the funnel, immediately on reaching the bottom of any considerable inclined plane, unless the speed is previously slackened or the regulator used with extreme care. Hence we may well doubt the applicability of this engine to long lines of railway; the defect seems to lie in the *principle* which apparently involves the necessity of wire-drawing the steam, and is not to be easily removed by any mechanical arrangement whatever. In the locomotive engine, in its most improved state, the steam is in fact throttled at both ends—that is, both in the *induction* and *eduction* pipes.

73. Notwithstanding that the boilers of the locomotive engines on the Stockton and Darlington railway have been generally modifications of the old, or Trevithick plan, with a much greater capacity in proportion to the heating surface, than the multiflue boiler of Mr. Booth, and therefore, generally considered to be on a less economical principle as to the application of heat, it is well known, that the cost to the company for drawing each ton per mile on the level, is not one half of what it is upon the Liverpool and Manchester

line. The fact is certainly not in favour of high speed and high pressure; the speed of the Darlington locomotives being about 12 to 15 miles an hour, which appears to be the velocity that gives the *maximum of useful effect*, while the pressure of the steam is only about 40 pounds on the square inch. And we have had an opportunity of ascertaining, from a long series of very careful experiments, that even this pressure is still higher than that which is found to produce the best possible effect in a stationary engine, when working without either governor or throttle valve, as is the case with locomotives.

The superior economy of the Durham engines, is, no doubt, in part, owing to the use of coal instead of coke, and not being compelled to burn their smoke, (as they are obliged to do on most of the Lancashire railways,) and this fact, it may be observed by the way, says nothing in favour of smoke-burning. It may also be stated, that but for the invention of the blast pipe, by Mr. Timothy Hackworth, which, in conjunction with Mr. Booth's boiler, at once doubled the efficiency of the locomotive engine, the prevention of smoke on railways would probably still present as great a difficulty as it yet does in factories.

While on this subject we may just state that the original "Sanspareil," of Mr. Hackworth, which all but successfully competed for the prize at the opening of the Manchester and Liverpool railway, may still be seen regularly working on the Bolton and Leigh railway, apparently not much worse for seven years' constant work, the boiler never having required any essential repair, while its contemporary rivals that have escaped the fate of the "scrap heap," have been re-made, and mended over and over again, since the celebrated race at Rainhill—a fact which goes far to prove that the principle of this engine has not been so very much improved upon, except that it is not so well calculated for burning coke as coal. The Sanspareil may frequently be seen at the

Kenyon Junction, waiting for the Bolton trains from Liverpool, and plans of it may be seen in Dr. Lardner's Work, Hebert's Mechanics' Encyclopædia, Wood on Railroads, The Mechanic's Magazine, and many other works.

PRIMING OF FACTORY ENGINES.

74. The steam in a common boiler, for working an ordinary condensing engine in a factory, is usually of about two pounds per square inch greater pressure than the average pressure on the piston throughout the stroke, and with this condition, we have never found an instance of a boiler having much less than half a cubic yard for steam room per horse power, that was able to do its work properly. This proportion may be depended on, as the result of no very limited experience, being from actual personal examination and measurement of several hundred boilers, with a view principally to the determination of this particular datum; and it fortunately happens, that the circumstance of a boiler priming into the cylinder, not only gives visible and audible signs of its taking place, but also leaves, in some measure, permanent traces of its having done so, sometimes in the cylinder, but almost always in the boiler, so that the accuracy of our experiments on this head may be easily tested.

Where the engine, or rather the boiler, is overworked, and the load on the engine not very regular, experiments to the foregoing effect may be said to be going on almost daily, and in many cases, even without the owner being aware of any thing of the kind, until his engine has been broken down a few times, and after the expenditure of a few hundred pounds; then (as it is commonly, but expressively, said in Lancashire) "*he finds it out.*" In fact, the want of sufficient capacity of steam chamber entails upon us the choice of two evils; one is the risk of breaking some part of the engine (generally the crank or crank pin) by a sudden flush of the water into the cylinder, the other is the constant tear and wear, and eventually the danger of bursting the boiler, by too great a pressure of steam.

75. Instances are sometimes met with, where double the above proportion of steam room (Art. 74.) is not sufficient to prevent the boiler from priming occasionally, but there are in such cases always some special circumstances to account for it; for instance, where there has been any neglect in cleaning the boiler, and a considerable portion of the load is suddenly thrown on, when the engine is already running at a good speed, and particularly if there is at the time a sharp fire under the boiler capable of suddenly generating a great quantity of steam. This, it will be perceived, is nearly a parallel case to that of a locomotive at the foot of an incline, as already mentioned. Cases of this kind frequently occur at calendar houses, saw mills, and machine shops. In the latter it is rather disgraceful, because the managers of such places, if not engineers, ought, at least, to be experienced mechanics; but in Lancashire there are more than two or three such concerns which seem determined to verify the old saying, that "shoemakers' wives go the worst shod." Mere neglect may be sometimes excusable, but there is too often sheer ignorance of the worst kind. Some of their proprietors have for years been acknowledged as the first mechanics in Europe, and justly as they may lay claim to be so considered, from the magnitude of their establishments, it is painful to find that they have much to learn in respect of their engines and boilers.

76. The presence of some kinds of dirt in the water, particularly if it be of a mucilaginous nature, is liable to cause the engine to prime whatever may be the amount of steam room. A small quantity of soap has a wonderful effect in this way; and generally speaking, with a dirty boiler and a full load on the engine, there is a *continual* "*flushing*" of the water in the boiler, or an *attempt* to "prime" at every

stroke of the engine. In these cases we usually find that the dirt has partially left the boiler and passed into the cylinder, thereby seriously injuring the packing of the piston and valves, and causing an immense waste of tallow and fuel, besides requiring perhaps two engines to do the work of one. We know of nothing that has been so detrimental to, and so long delayed the successful introduction of Mr. Barton's metallic packing for pistons, — decidedly the most important improvement in the steam engine since the days of Watt.

For all such cases, however, there are various preventive remedies, which will come more properly under our consideration in another chapter; the principal of which are the adoption of various mechanical methods of frequently cleaning out the boilers, or rather of preventing them from becoming dirty. We shall now advert in particular to an apparatus, which effects the latter purpose very completely without the necessity of emptying the boiler, and without the least interruption of the continued working of the latter, or the engine to which it is attached. And we shall endeavour to do so here, at the unavoidable risk of being thought egotistical, the apparatus in question being partly contrived, or rather improved, and wholly adapted to its present purpose by the author of this work; not only because it has an important relation to the subject now in hand, namely, the priming of steam engines, but also because, since the publication of our first edition, we have had reason to believe that the apparatus is not so well known, and where known, not so well understood as we had previously supposed.

INVENTION OF THE SELF-ACTING CLEANSING MACHINE FOR THE PREVENTION OF PRIMING.

77. In a very favourable review of this work in the Civil Engineer and Architect's Journal for December 1837, it

is properly stated, as a well known fact, "that the engine primes in proportion as the water is dirty, and the remedy is to empty the boiler and clean it out."* So perfectly true is this with respect to boilers under ordinary circumstances, and so great are the evil consequences generally arising from having foul water in boilers, that the great cause of complaint amongst all who have been concerned with the management of engines, has always been the difficulty of resorting sufficiently frequent to the operation of cleaning out. Persons who have only a superficial acquaintance with the steam engine, and who treat the boiler merely like a large culinary utensil, are apt to conclude that, provided the boiler is occasionally swept out, so as to prevent any adhesion and consequent burning out of the iron, nothing more is needed; but the experienced operative knows very well, that, if his engine be heavily loaded, and his boiler supplied with the ordinary water to be found in large towns, which usually contains a greasy or slimy kind of dirt, then, instead of the boiler bottom being in any danger of burning out from this cause, he will seldom find much dirt upon the boiler bottom itself, but by far the greater portion will be found sticking up against the roof, or inside of the top of the boiler, and against the back end, but always *above* the surface of the water. We frequently find the dirt in this manner spread over a very considerable area to the thickness of a couple of inches, and much thicker in some particular places, such as in the angles and about the straps to which the stays are attached.

78. Being impressed with the importance of attending to the above considerations, as regarding obstacles which seemed to lie at the root of all further improvement in the

* The Civil Engineer and Architect's Journal, Vol. I. pages 37, 121, and 178. London, 1838.

steam engine, and besides being convinced by repeated experiments, that in all cases there is a great saving in fuel and tallow by cleaning out the boiler once a week instead of once a month*; we became of opinion that if means could be devised for cleaning out a boiler *daily*, or oftener if needed, without wasting much hot water, a great desideratum would be accomplished. With these views we commenced, nearly a dozen years ago, the solution of the following problem, namely:—How to clean out a boiler without having it emptied and without stopping the engine, and thereby to supersede as far as possible the disagreeable necessity of sending men inside for that purpose?—Now this was not a question to be easily answered off hand, neither was its direct solution to be evaded by some lucky thought, such as contriving a particular shape of boiler for the purpose, but the invention, to be useful, must be applicable to all sorts of boilers. Consequently there appeared to be no method of procedure so likely to be successful as the old one of the mathematicians in all cases of difficulty, namely, that of *trial and error*; accordingly that was the method resorted to on this occasion; and as might be expected, although success was eventually sure, it came slowly, and in August 1829, the first complete cleansing machine was applied to a 20 horse boiler belonging to Thomas Marsland, Esq., M.P. for Stockport.

79. Of course the first machine made, as we expected at the time, only partially answered the purpose of keeping the boiler clean, but it did so sufficiently well to completely prevent the priming of the engine, and was so far effective in other respects that the boiler was found to be

* A period of *three days* was recently found to be the utmost limit that could be allowed, at a factory near Stockport, without the engine priming, although there were two 50 horse boilers to one 70 horse engine.

cleaner at the expiration of thirteen weeks' continued working than it had been before at the end of two. From continual and gradual improvements upon almost every new machine that was made during the succeeding seven years, accompanied, as may be supposed, by not a little labour and many disappointments, the apparatus was at last rendered perfect. Indeed for the last three years, so far as it is required to free a boiler from mud, sand, clay, salt, or *loose* sediment of any kind whatever, we can pronounce the cleansing machine to be quite perfect and admitting of no further improvement. There are at this time, 1839, nearly one thousand of these machines in use, principally in Lancashire, Yorkshire, Durham, and Northumberland, so that any considerations in the construction of a boiler, with a view to the necessity of a man going inside to sweep it out, may be safely discarded.

Mr. Marsland of course deserves the credit of being the first amongst the very few manufacturers who were willing to allow the apparatus to be tried at all, and he has, or rather the firms with which he is connected have, now, at their extensive cotton and print works, no fewer than sixteen of these machines at work, which have been made at various times during the progress of the improvements. This gentleman was also the first manufacturer in this district to try Mr. Samuel Hall's patent method of condensing without injection, which by enabling the boiler to be supplied with distilled water, also offered apparently the only plausible means of preserving the boiler. The plan, however, as is well known here, totally failed, and was given up, after long and very expensive experiments at Messrs. Marsland's Portwood Mill, in Stockport*.

80. The first cleansing machine for a locomotive boiler

* This was Mr. Hall's second patent for the same object; his first had been previously tried at Mr. Sherratt's foundry, in Manchester.

was made for Messrs. Galloway, Bowman, and Glasgow's engine, the Caledonian, belonging to the Liverpool and Manchester Railway Company, in 1833. This engine was the first locomotive that was made with the boiler oval in section, and was worked with great success for some years as a bank engine on the above railway. The first complete machine for a marine boiler was made in 1834, and the apparatus was fully proved to act well in the City of Dublin Company's steam-packet the Shamrock, in the summer of 1835; this vessel we believe being the first which had the cylindrical marine boilers with numerous tubular flues, which boilers, we may here remark, are the only kind that are capable of bearing any considerable pressure of steam, without which the advantage of working steam expansively is, at the best, questionable in *commercial* steamers.

81. We are thus particular in stating the above facts, because since the publication of the first edition of this essay we have had sundry applications from various quarters, both in this country and the continent, respecting the cleansing machine; and it may save some trouble to parties at a distance in being informed, that the cost of the machine in Manchester is from £12 to £15. It has been entirely uphill work to bring this invention to its present state of perfection, while the author acknowledges that his perseverance was not a little stimulated by many first-rate scientific mechanics pronouncing his task to be hopeless. He would advise his brother mechanics who may have similar obstacles to encounter, to pursue the object they may have in view, and equally avoid having any connection with either *patents* or *patrons*, unless the latter make their first appearance in the shape of customers. Many of our applicants have expressed great surprise at not having heard of the apparatus previously, through some of the scientific publications; we can assure them, that if they delay the adoption of improvements until

they are sanctioned by the approval of the editors of scientific journals, they may safely calculate on being at least ten years behind their brother manufacturers in this country. The most successful manufacturers in Lancashire do not generally look into books for improvements in machinery, and still less do they consult the advertisements of inventors and patentees for that purpose.

82. No doubt the best policy of the mechanical engineer in regard to the propriety of adopting improvements in any kind of steam engine apparatus, is that ascribed to Mr. Field in his fitting up of the Great Western steam-ship, who, it seems, preserved "a prudent mean between the rejection of all untried expedients on the one hand, and the rash adoption of crude projects on the other."* But it is no very easy matter, for even the best informed engineer, to hit this happy medium;—very great talent, as well as much labour and research, must be necessary to enable him to avoid being frequently egregiously deceived by some of the immense multitude of inventions that are constantly offered to his notice; amongst which it may also happen to be far from being an *untried* scheme that is entitled to be considered a *crude* project. The most crude and clumsy of projects, and those which have been tried and laid aside scores of times, are constantly being revived and re-patented; and when brought out in connection with a long purse are almost sure to take at first; while the real mechanic who makes useful practical improvements, may struggle in obscurity for a lifetime, unless he resort to that advertising quackery which gives to the worthless inventions of his rich competitor nearly all their éclat. It is surprising what a progress a clever monopolising patentee will make, in a very short space of time,

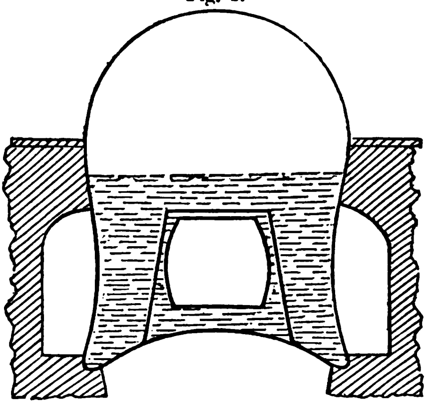
* From the article "Ocean Steamers," in the Monthly Chronicle for July, 1838, supposed to be written by Dr. Lardner.

with a railway or steam navigation company, as compared with his almost uniform want of success with the enterprising cotton spinner, who rarely deputes any subordinate agent to *think* for him on the expediency of adopting any new plans, however well such agents may be able to manage the old ones.

THE BOULTON AND WATT BOILER.

83. It is very commonly stated, that Mr. Watt allowed 25 cubic feet of space in the boiler for each horse power: how the assumed authority of Mr. Watt was first attached to the statement, does not appear, but it is certain that Mr. Watt never left any opinion to that effect on record; and it is no less certain that the practice of the present firm of Boulton, Watt, and Co., gives no sanction whatever to such statement. Nevertheless it is so stated in several popular elementary

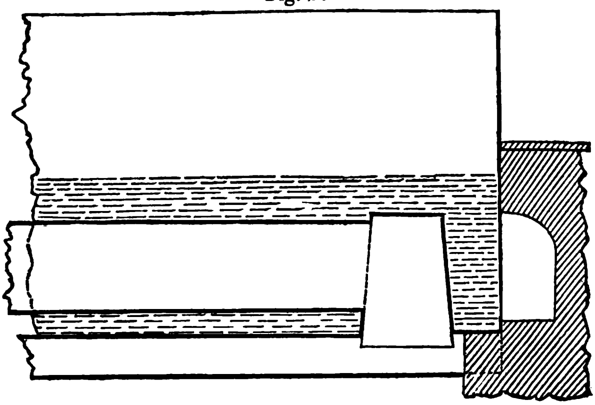
Fig. 4.



works which have been published during the last fifteen years, professedly for the instruction of working mechanics; and the fact serves to shew, how the writers of books who obtain all their knowledge from books alone, are apt to mislead one another, especially on the subject of steam; for where they find an opinion current, which they are unable to trace to any philosophical principle, they can easily cut the matter short by saying, "*Watt and Bolton*" said so and so, not caring, perhaps, how the assertion may affect the well earned reputation of one of the greatest benefactors of his age.

84. It is not improbable that the above error may have had its origin in the fact that a Boulton and Watt 20 horse boiler,

Fig. 5.



as usually constructed by them, will just occupy a parallelopipedal space of nearly 18½ cubic yards, or measuring by its extreme dimensions in length, width, and depth, about 500 cubic feet, and which divided by 20, gives just 25 cubic feet of "space" for each horse power; but this, of course, is "*space*" *for stowage*, or room for the boiler to stand in, and not *inside* "boiler room," as usually understood.

85. There is only one other way in which this common error could have obtained currency, and that is by some one mistaking a 30 horse boiler for one of 20, from the ordinary practice of putting down a 30 horse boiler, to a 20 horse engine. Now Boulton and Watt's 30 horse boilers are of the wagon shape, and usually 5½ feet wide, 7½ deep, and 15

long; with an inside flue of 1 foot 8 inches across the top; this according to the approximating rule for flued boilers in article 12, would be considered, in Lancashire, as equal to—

$$\frac{(5 \cdot 5 + 1 \cdot 666) \times 15}{5} = 21 \cdot 499$$

or about, 21½ horse power; and if we calculate the *cubic capacity* of the boiler, including the flue tube, from the same dimensions, we shall find it to be about 18¾ cubic yards, or very little more than 500 cubic feet, and this, supposing it to be taken for a 20 horse boiler, is just 25 cubic feet per horse power, shewing the same result as before. Figure 4 is a cross section of a Boulton and Watt boiler; and figure 5 is a longitudinal section of part of the same boiler, shewing the uptake of the inside flue.

86. With respect to the effect which the propagation of the above assumed rule for boiler room, has had on the practice of boiler making generally, there is no doubt but it has been beneficial; for makers and users of boilers have been naturally induced not to depart very far from what they considered Boulton and Watt's standard. We have, in consequence, a great number of boilers of all the various forms in actual use, ranging within 2 or 3 feet above and below the proportion of 25 per horse power, from which an average proportion can be obtained far more nearly correct than could have been expected, if the practice of engineers had varied at random, or to a greater extent, on either side of this imaginary standard, which, accidentally, turns out to be very near the correct proportion. A comparison of a great number of cases has convinced us that those which are a little above 25 cubic feet, say 26 to 27 cubic feet per horse power, are the most economical in the long run, and the latter number is fixed upon from its being a convenient unit measure of capacity.

It may be asked how we are to reconcile the above conclusions with the generally acknowledged effectiveness of Boulton and Watt's boilers, seeing that they have not more than two-thirds the usual proportion of capacity given by some other engineers, and which we have found to give the best results in practice. This question admits but of being answered in one way, and that is, by a reference to the practice already alluded to, of rating the boilers at one-half more than the power of the engines they are intended to drive.

In thus referring to the practice of the celebrated firm of Boulton and Watt, we do not profess to have any knowledge of the rules they use in the proportioning of their boilers, otherwise than by means which are open to others: that is, by measuring a great number of the boilers, and knowing their capabilities. The proportions used by other steam engine makers, we have also preferred to obtain in the same way, although kindly offered all the necessary information on the subject, by several of the first houses in the trade; but most men of business are reluctant to have their rules published, and justifiably so; besides, it might appear invidious to publish those of any of the leading houses, to the exclusion of others.

87. There is a very prevalent error relating to the form of wagon boilers, or their proportions as to length, width, and depth, which is frequently to be met with in books, and almost always coupled with the recommendation as to capacity already disposed of. In a recently published mathematical work, of a class generally very superior to the many popular works alluded to, a rule for finding the proportions of a steam boiler is thus given: "Take the width as 1, the depth 1·1, and the length 2·5, and allow 25 cubic feet per horse power." Now in order to shew that the principle on which all such rules are founded is entirely false, it is only

necessary to consider, that the areas of the surfaces of bodies are as the squares of their lineal dimensions, while their solid contents or capacities are as the cubes of the same; consequently, any two boilers, or other vessels or bodies, which are of the same form or proportion as to their lineal dimensions, will have their capacities as the squares of their respective surfaces. Hence, if we fix on a boiler of any particular dimensions as a model, or one which we have found by experiment to be in the best proportion, and afterwards construct another on a larger scale, say, for instance, just double the lineal dimensions of the first, we shall find that although it has only *four* times the area of heating surface of the first, or model boiler, yet it has exactly *eight* times its cubic capacity—and therefore it will have just double the quantity of water which it ought to have, in proportion to the heating surface.

Any further demonstration of the absurdity of this frequently quoted "rule," is not at all requisite for the working mechanic, as the latter is a piece of instruction which no boiler-maker who knows any thing of his business is at all likely to follow. The most ordinary workmen, although unable to express it in mathematical language, are sufficiently conversant with the principle it involves. But as one of the best, and we may say the very best, of the popular works before alluded to*, in introducing the well-known table of *experimental results* by the French Academicians, on the elasticity of steam at high temperatures, says, "the practical man will duly estimate the value of this *gift of science*," it is just possible that the rule in question may be thought by some of its authors, or rather editors, to be another gift of science, it will be useful if we enable the artisan to evince

* The *Mechanic's Calculator;* comprehending principles, rules, and tables, in the various departments of mathematics and mechanics; useful to millwrights, engineers, and artisans in general, by William Grier, Civil Engineer, Glasgow, 3rd edition. 1836.

a just proportion of gratitude by testing its value in plain arithmetic, which is the only proper neutral ground for "common" mechanics and mathematicians to meet.

88. In the work just quoted, we have an example of this method of computing the power of a boiler 5 feet wide, $5\frac{1}{2}$ feet deep, and $12\frac{1}{2}$ feet long; and the whole content of the boiler is stated as follows:

$$5 \times 5{\cdot}5 \times 12{\cdot}5 = 343{\cdot}75 \text{ cubic feet,}$$

and that according to Boulton and Watt's estimate of "25 cubic feet of space in the boiler for each horse power."

$$343{\cdot}75 \div 25 = 13\tfrac{3}{4}$$

is the number of horses power of the engine for which this boiler would be fitted.

Now the precise form of the boiler is not mentioned, but from the method of computing its internal capacity, we must infer it to be rectangular in section, or a parallelopipedal box or chest, and if we suppose one half of its external surface to be heating surface, we have—

		Sq. Ft.
For the bottom surface........	5 × 12·5	=62·5
Half the two sides	5·5 × 12·5	=68·75
Half the two ends	5·5 × 5	=27·5
The total heating surface...........		158·75
Which divided by the horse power		13·75

gives rather more than $11\frac{1}{2}$ square feet of heating surface per horse power.

If we now take another boiler, of exactly the same form, but of twice its lineal dimensions, or 10 feet wide, 11 deep, and 25 long, its capacity will be—

$$10 \times 11 \times 25 = 2750 \text{ cubic feet.}$$

And using the same divisor as before, it is equal to—

$$\frac{2750}{25}=110 \text{ horse power.}$$

Then taking one half the external surface for the heating surface, as in the former case, we have—

		Sq. Ft.
For the bottom surface............	$10\times25=$	250
Half the two sides	$11\times25=$	275
Half the two ends..................	$10\times11=$	110
This sum ÷ by the horse power		11,0)63,5
Gives		5·77 square feet

per horse power, which is exactly one half the proportion of the former.

CONCLUSIONS REGARDING BOILER ROOM.

89. From what has appeared we might safely assume, that the space for *steam* in a boiler, *ought not to be less* than half a cubic yard per horse power, and that the space for *water* certainly ought not to be *more;* therefore, generally, a cubic yard may be stated as the necessary capacity of boiler, for each horse power. There are certainly cases, especially where the water is dirty, as we have already shewn, in which this proportion of steam room is not sufficient, and there would not be any great disadvantage in generally having the steam chamber considerably larger, excepting from the waste of heat arising from condensation and radiation, and the expense and inconvenience of having it larger than absolutely necessary. But our business at present is only with ordinarily well managed factory boilers, that are supplied with good water and kept moderately clean; and with such we hold that half a cubic yard ought

to be considered the minimum of steam room for each horse power.

90. In enunciating the above proposition, we disclaim any right to being its first promulgator; for we know that there is a current saying amongst the engineers in the neighbourhood of Newcastle-upon-Tyne, that a *good* steam-engine ought to have an area of piston equal to 27 circular inches per horse power, while the boiler ought to have 27 cubic feet for the same. This is, probably, one of those maxims which occasionally become established in any trade where there is a good deal of practice, and it is, at least, as old as the first introduction of Boulton and Watt's patent engines to the collieries, in the counties of Durham and Northumberland.

In so wide a field for experience in the application of steam power to a *uniform kind of work*, the above maxim might be supposed to have some *a priori* claims to be considered very near the truth. We have, however, been careful not to allow any such considerations to influence our opinions; besides, our experiments and observations on this subject, have been for a number of years principally confined to the engines and boilers in the cotton mills of Lancashire, where also, from a *uniformity of work*, which is an important requisite, (when drawing deductions from an average of a number of experiments,) we have a similar field for experience, to that presented by the collieries in the north of England, but with considerably greater facilities for investigation and comparison.

These advantages arise, partly, from the greater concentration of the cotton spinning business in large towns, where the constant interchange of opinion amongst the engineers and managers of the various factories, tends to produce a certain degree of uniformity of management, while the rivalry of competition will not allow any to lag very far behind their neighbours. It may also be stated, that the workmanship of the engines and boilers in Lancashire is of a very superior kind, compared to that in the coal district.

91. The only district affording equal facilities for improvements in steam engineering, besides the two above referred to, is Cornwall, from which county we have had statements which have had the effects of gross exaggerations as to the economy of the Cornish high pressure engines. From some recent investigations it would appear, that the average expenditure of fuel in the Cornish engines is about *six or seven* pounds per horse power per hour; and that in this county, as we have already shown, it is about *ten:* the difference is easily accounted for, by the system of working expansively, which is capable of being carried to a great extent in pumping engines. That there is nothing in their system of management, or in the form of their boilers, that can be profitably imitated here, any one may be convinced by consulting Mr. Wicksteed's report, published in the first volume of the Transactions of the Civil Engineers: and in which will be found, plans and sections of the latest improvements in the Cornish boilers*.

92. In stating the quantity of boiler room necessary for each horse power, we do not mean to insist that it does not admit of some little latitude, in which the difference in effect is hardly perceivable, but the correct proportion is much more capable of ascertainment, than persons unused to such researches may expect. It may surprise some mechanical engineers, who have been accustomed to calculate to the fraction of a horse power, to be told, that the power of the steam engine itself can, in general, only be approximated to

* Transactions of the Institution of Civil Engineers, Vol. I., London: Weale, 1836.

in a very rough way, compared to which, the properly calculated power of a boiler is exactness itself. This arises from the friction of an engine, which, although capable of being ascertained within moderate limits for any assigned moment, is of that fluctuating character, and withal so large a portion (from one sixth to one half) of the whole load, that there is nothing about the data of a boiler to be compared to it.

We have already shown (Chap. I.) that the evaporating power of a boiler is a certain function of the heating surface and area of fire-grate, combined with constant quantities expressing the peculiar heating qualities of the fuel, which can be ascertained experimentally, to any degree of exactness required. Thus the principal elements of the power of a boiler admit of exact mathematical calculation; and there is no doubt that the remaining ones, which chiefly regard its application to any particular kind of engine, or its capacity for steam and water, also admit of the most rigid determination upon mathematical principles.

93. It is also much more easy to acquire a knowledge of a number of experimental truths on this subject, by a very little observation and attention, than is usually supposed, and without *directly* instituting experiments, or wasting time on what is generally understood by *experimenting*, which is well known to be frequently little better than playing with models.

As a description of the best mode of experimenting on a large scale, we may suppose, which is a very common case, that any given steam-engine has two boilers, with which it is worked alternately, each having the same evaporating power, and in all other respects similar, except as to capacity, one of them having twenty, and the other twenty-five cubic feet per horse power, (reckoned by the evaporating power of the boiler,) of course a direct reference to the coal account will give the comparative economy of the two boilers, and which we will suppose to be determined in favour of the larger one. Again, suppose in another similar case we find that the proportional capacities are respectively twenty-three and twenty-seven cubic feet per horse power, and that it is again determined that the larger boiler works the engine with the least quantity of coal, we are then assured that the true proportion is above *twenty-five cubic feet per horse power*. Now if we take other two sets of observations on boilers, whose capacities are considerably above what we suppose to be near the truth, say thirty or forty, or any other number of cubic feet per horse, and compare them in a similar way, we soon arrive at the fact, that the best proportion lays between twenty-five and twenty-nine cubic feet per horse power; and by proceeding in this manner, as opportunities for observation occur, we may approximate to the true proportion as near as ever we like.

94. There remains to be noticed one more popular rule respecting boiler room, which prevails in Lancashire, and that is, "for each *square inch* on the piston allow a *cubic foot* in the boiler." Now if the cylinders are of the ordinary proportions, it will be seen that this is little more than three-fourths of what we have concluded on above as the best, and which is more nearly at the rate of a cubic foot to a *circular* inch.

This rule is principally confined to the makers of small high pressure engines, from two to six horse power, which are used for a great variety of purposes, where economy of space is of more consequence than economy of fuel; and where, for the same reason, the engines are made with very short strokes, in proportion to the area of the cylinders. We may observe, that this rule gives, perhaps, not an ineligible proportion where engines are working in pairs, as in steam-boats and railway locomotives; and from the fact, that some of the best engine-makers have recently erected several of those "sister engines" in the cotton factories, with an amount of boiler room approaching to this proportion, it is on that account deserving of some consideration. By the way, we may just state, that if *three* sister engines could be conveniently connected, it is possible that the expansion system of the Cornish pumping engines, might be advantageously applied in cotton mills.

95. It is, however, necessary to bear in mind, that our object is, first, simply to determine the best proportions for the boiler of a *single* double-powered condensing engine, and without complicating the subject until the data for this object is fairly established. For similar reasons, it may be as well to take for granted a few other particulars, and which will also tend to prevent the misapplication of some of our rules, in some parts of the kingdom: one of these is, that the boilers are to be considered as made of the best wrought iron plate, averaging $\frac{3}{8}$ of an inch in thickness, say 7-16ths for the bottom, $\frac{3}{8}$ for the sides, and 5-16ths for the top, which is the ordinary practice of the Manchester boiler makers.

FACTORY CHIMNEYS.

96. Another, and a most important particular is, that the chimney should have sufficient power to command a draught equal to about half an inch of water in a pressure gauge inserted in the bottom of the chimney, or from $\frac{3}{8}$ to $\frac{5}{8}$, according to the weather, and other circumstances. The *Pressure Gauge* for chimneys is a small glass syphon, exactly the same as that used in gas works, only its action is the reverse way—the little column of water being drawn inwards instead of being pressed outwards.

Respecting the best construction of a chimney for obtaining a good draught, the greatest possible difference of opinion exists among scientific men, and until a scientific theory of heat and combustion is discovered, which will explain all the facts known, it will be difficult to define strictly, the principles on which the velocity of draught through a furnace depends. The subject was a good deal discussed in the scientific journals some years ago, by Mr. Sylvester, Mr. Davies Gilbert, and others, some of the first mathematicians in England; but most decidedly without producing any results on which any prudent engineer can depend. Mr. Tredgold was the only one who ventured to draw from his calculations a rule for the guidance of the factory engineer; but, unfortunately, those who have been guided by it, have got farther wrong, than it was possible for the most ignorant workman to do without any rule whatever.

97. It is considered by those who have had the most practice, that in an engine chimney from 24 to 30 yards high, the common rule of making them 20 inches square inside at the top (400 square inches area) for each 20 horse boiler, is a good proportion. In Manchester, where, until lately, the engine chimneys were from 24 to 36 yards high, we always found the velocity of draught to be nearly proportional to the capacity of the chimney, reckoning by its narrowest dimensions; and have since observed, that the draught *is not improved* by raising the chimney much above 40 or 50 yards, unless the width is also increased in a certain ratio. On the other hand, in chimneys under 20 yards high, if the width is greater than the above proportion, the draught is *worse* for it. At all factory chimneys we would strongly recommend the use of the *pressure* or *draught gauge,*—an instrument of as much use, in testing the effect of any alterations, as the water gauge, or even the steam gauge itself.

EXAMPLE OF RE-SETTING A BOILER.

98. As a practical example of applying the foregoing

principles and deductions, we shall now proceed with the investigation of the badly proportioned boiler, described in the commencement of this chapter, (art. 61,) from the dimensions there given, its capacity may be found as follows:—

The semi-cylindrical top is equal to—

$5^2 \times \cdot 7854 \times 20 \div 2 = 196 \cdot 35$ cubic feet, or 7·27 cubic yards.

The water room is $3 \cdot 5 \times 5 \times 20$ ($= 350$) less by 1-9th for the arched bottom, = 311·11 cubic feet, or 11·52 cubic yards.

Hence we see, that although the total capacity of the boiler is equal to $11 \cdot 52 + 7 \cdot 27 = 18 \cdot 79$ cubic yards, or nearly 19 horse power, yet the steam room is only sufficient for $7 \cdot 27 \times 2 = 14 \cdot 54$ horse power, while the water room is equal to $11 \cdot 52 \times 2 = 23 \cdot 04$ horse power.

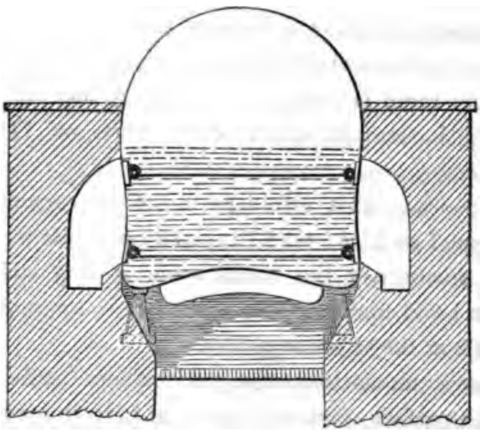
The above calculations, along with those made before for the heating surface, (art. 61,) give the following results:—

Capacity....................	19	cubic yards	= 19	horse power.
Steam chamber	7·27	do.	= 14½	do.
Water chamber	11.52	do.	= 23	do.
Effective heating surface........................	16·33	square yards	= 16⅓	do.

99. Supposing that it is expedient to enable this boiler to work a 20 horse engine with the least possible waste of fuel it might appear that the most feasible plan would be, to begin with equalising the steam and water chambers, by lowering the water surface; but this would render it necessary to lower the brick work of the side flues, and would thereby diminish the heating surface, which is already too small. We must, therefore, proceed in a different manner, and endeavour to increase the area of the bottom surface first, which may be done, to its utmost extent, by taking away the whole of the seating bricks on each side of the

furnace and flame bed, and re-setting the boiler upon 6 cast iron pillars, as represented in fig. 6; this will gain 9 inches

Fig. 6.



on each side, or about 30 square feet of bottom surface, less by the surface occupied by the 6 pillars, and the brick work with which they ought to be surrounded, say about 4 square feet; we must also deduct the small space to be covered with brick-work near the bottom of the side flues, say 3 inches deep along each side, equal to 10 square feet in area; one half of this only, or 5 square feet being effective. Therefore we have $30-(4+5)=21$ square feet, or 2·33 square yards of additional effective heating surface gained, which added to 16·33, as before found, gives 18·66 square yards.

100. We also found the quantity of water to be equal to 11·52 cubic yards, or $(1{\cdot}52\times 27=)$ 41 cubic feet more than it ought to be for a 20 horse boiler; we must therefore now proceed to take this surplus water away: if we divide the surplus water by the superficial area of water surface

(20 × 5 = 100 square feet,) the quotient will give us its depth, or

$$\frac{41}{100} = \cdot 41 \text{ feet} = 5 \text{ inches.}$$

As there is already 6 inches in depth of brick work, between the surface of the water and the top of the side flues, there will still be 1 inch, when the surface is lowered by the above amount, but there ought never to be less than 2 inches; therefore, the flues may be covered in 1 inch lower all the way round, and the vertical surface will thus be reduced by 50 square inches, half of which only being effective, it is $\frac{25}{144}$, or less than $\frac{1}{4}$ of a square foot, still leaving the effective heating surface above $18\frac{1}{2}$ square yards.

101. The proper area for a fire-grate for a 20 horse boiler, with this amount of heating surface, can be found by the slide rule, as directed in the last chapter, (art. 54,) or the formula, as follows:—

$$F = \frac{P}{S} = \frac{20^2}{18 \cdot 5} = \frac{400}{18 \cdot 5} = 21 \cdot 6 \text{ square feet;}$$

and the corrected proportions of the boiler will stand thus:—

Steam room	7·27 + 1·52 = 8·79 cubic yards	= 17·58	horse power.
Water room	10· do.	20·	do.
Effective heating surface	18·5 square yards	20·	do.
Area of fire-grate	21·6 square feet		

By comparing this with the former calculation, (art. 61,) it will be seen that the proportions are considerably improved; the steam room being increased and the quantity of water lessened; and at the same time, with an increase of the effective heating surface.

CHAPTER III.

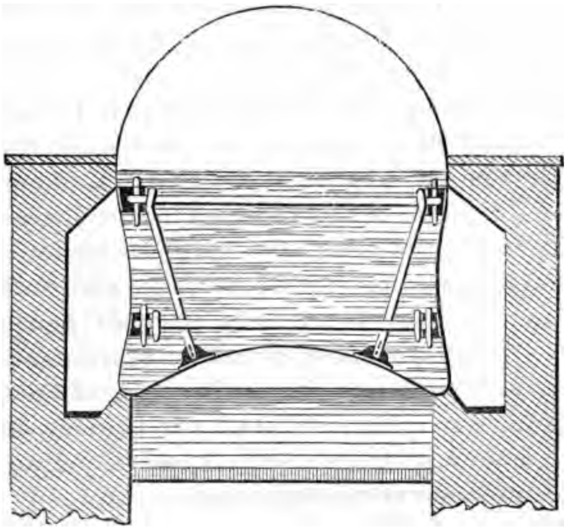
ON THE EFFECTS OF LARGE BOILERS; ALSO ON THE DISPOSITION OF THE WATER CHAMBER, WITH METHODS OF REDUCING ITS CAPACITY AND SAVING FUEL.

102. HAVING determined the proportions necessary to be observed in a good steam boiler, as regards its steam chamber and heating surface, we have, in the last chapter, seen how far those proportions may be departed from, by giving an analysis of what would be called a 20 horse boiler, according to one of the common modes of reckoning in Lancashire; and having also shewn a method of correcting its deficiencies, or improving it, so far as it is susceptible, in the best way short of pulling it out of its place and putting in a new one, we shall resort to the same mode of illustrating the subject of this chapter.

The above-mentioned nominal 20 horse boiler, was constructed in the proportion of *five* square feet of water surface per horse power; we shall now, with a similar object in view, take an instance of one with an allowance of *six* square feet per horse power; say 17 feet long, 7 wide, and 8 deep, a transverse section of which is represented by the opposite diagram fig. 7. These cases are not exactly supposed ones, but samples of many that have been the subject of direct experiment, and to which, one or more of the rules and methods of treatment recommended in this work, have been actually applied.

103. In choosing this method of investigation, we shall

Fig. 7.



endeavour to inculcate principles by applying them to practice, although fully aware of the usual charge, as well as of the danger, of drawing conclusions from isolated facts and experiments; it may, however, be said, that although this empirical mode of instruction, by example rather than precept, may not be liable to very serious objections in teaching the mere elements of knowledge, as it is, in fact, the only successful mode of thoroughly instructing those who wish to learn any mechanical trade, yet that at any rate it is "unscientific." To this we can only reply that it is not "un-English," for we are told that Brindley raised the first canal aqueduct in the world, in defiance of all the rules of science of the day; and in the same locality we have seen Stephenson successfully lay an iron railway across Chat Moss, quite contrary to the opinions of all the learned; and to compare small things with great, if we succeed in assisting the English manufacturer, or artisan, to obtain the greatest amount of power from a steam-engine, at the least possible expense, we may safely continue to leave to the French and continental writers, all abstract speculations on the subject of steam, as more suited to the closet of the philosopher than an English workshop or manufactory.

Notwithstanding the general inclination of the capitalists of the present day to listen only to the plausible theories of scientific men, all who are experienced with the practical details of any kind of manufacturing industry, will agree in the propriety of this mode of treating *this* subject, as being more consonant to the manner in which nearly all useful *practical* knowledge is originally attained: besides, each example chosen is not to be considered merely as an individual case, but an average of a very large class of cases, which may be found every day, so that all who have any pecuniary interest in the matter, have ample means of judging of the general correctness of our statements.

Although most of the foreign investigations on this subject are of far too speculative a character to be of any immediate utility, we ought, however, in justice, to mention a splendid exception in the late experiments on the explosion of steam-boilers, by the Franklyn Institute of Pennsylvania, made by order of the American government*; those experiments being alike distinguished for the original talent employed in their execution, as for their general practical bearing and humane tendency.

WATER ROOM.

104. In fixing on the proper capacity for the *water* chamber of a steam-engine boiler, there are not such peculiar difficulties, as in the case of the *steam* chamber. It is generally agreed that, for the former, ten or twelve cubic feet per horse power is as little as ought to be allowed; Tredgold

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* The Report has been printed in the 25th and 26th Volume of that useful work, the London Mechanic's Magazine.

recommends not less than ten, in consideration of the feeding apparatus for water not acting with perfect uniformity, even if ever so delicately adjusted; but in fact, contrary to what Tredgold appears to suppose, it is usually found, that the feed-water enters the boiler with the greatest uniformity, when the feeding apparatus is not so *very* delicately adjusted, —for the float is then not so much affected with the occasional ebullition of the water. Mr. Tredgold, however, advises us to calculate upon the feeding apparatus being occasionally out of order, and therefore to err on the safe side; but as there are more causes for putting it out of order than he seems to be aware of, we shall not be far wrong if we take the capacity for water at a higher rate than his estimate.

105. We have elsewhere stated, that the water chamber ought to contain about 13½ cubic feet per horse power; and from some direct experiments, made by having large stones and other articles placed in boilers, so as to occupy a portion of the water room, (as represented in Fig. 10 and 11,) without altering the other conditions of the boiler, it has been proved that it ought not to be more, even for hard firing. It is one of the advantages of Mr. John Stanley's firing machine*, that it will keep the steam equally steady, with a less quantity of water than is required when the old mode of firing by hand is used; but owing to its keeping up a regular flame against the boiler bottom, the water is continually on the point of boiling, and therefore to prevent priming, the surplus room for water ought to be added to that for steam.

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* This machine, connected as it now is with Stanley and Walmsley's patent moving fire-bars, completely effects the important purpose of feeding and stoking the fire, *without opening the doors of the furnace;* besides apportioning the fuel very exactly to the quantity of steam required.

106. The priming of the engine is, also, not altogether unaffected by the quantity of water which the boiler may contain, inasmuch as a smaller quantity of water becomes sooner concentrated, or *thickened* with the daily accumulations of whatever dirt enters the boilers along with the supply water, either in solution or suspension, consequently very frequent cleaning of the boilers from its being a great preventive of priming, will, by enabling us to work with a smaller quantity of water, tend considerably to a saving of fuel.

107. It is a prevailing opinion, that after the steam is once got up, there is no material difference between keeping a large quantity of water boiling, and a smaller quantity, provided that the boiler is sufficiently clothed with non-conducting substances to prevent the escape of heat by radiation or conduction, but on this subject practical men differ; although, why they should differ in opinion on so plain a matter is unaccountable, for it must appear very evident that a large quantity of water will require more heat to *keep it boiling* than a smaller quantity, supposing of course the heat required to generate steam to be equal in each case. On the other hand, when there is too small a quantity of water, it is difficult to keep the steam sufficiently steady, it is then quickly up, but is as quickly down again, more especially where the old system of stoking and firing by hand is still in use; but where machine firing is used, (and where it is not it ought to be,) as it is now almost universally in Lancashire, a much less quantity of water will do than was formerly thought necessary.

108. It is quite clear, that the smaller the quantity of water, the less will be the expenditure of fuel during the first getting up of the steam after each stoppage of the engine. Some idea of the quantity of fuel required for this purpose

may be formed from the consideration of the well-known fact, that it requires about one-sixth of the quantity of fuel to heat water up to the boiling point, which is necessary to boil the same quantity of water entirely away, or about 14 per cent. of the whole consumption. We have already, from quite different considerations, estimated the proportion at about 15 per cent. (Art. 9); but whatever may be the exact amount, it is well known to be in direct proportion to the quantity of water in the boiler, and that it is sufficiently considerable to make it an important item in the expense of a steam-engine.

Now, if we suppose that a boiler contains only one-third more water than is absolutely necessary, it appears from the above, that there will be on that account, a direct loss of 7½ per cent. upon the whole consumption of a Factory Engine; or for 100 horse power, say 6 or 7 tons per week, which is equivalent in the manufacturing district to upwards of 150*l.* a-year. It may seem incredible to some, that so large a portion of fuel may be wasted from this cause, but it is sufficiently evident from theory, and has been abundantly proved in practice.

109. Mr. William Elsworth, the well-known able engineer of the extensive cotton-works of Messrs. Horrocks, Miller, and Co., of Preston, some time ago ascertained by several careful experiments, that the mere circumstance of keeping the boilers cleaner than is generally done, is capable of reducing the time of getting up the steam by at least one-third; and consequently, also reducing in the same proportion the consumption of fuel used for that purpose, which in their case was very considerable, owing to the circumstance of Mr. Elsworth preferring to work with a greater quantity of water in the boilers than is usual in other parts of Lancashire. It may be here stated, that Messrs. Horrocks, Miller, and Co. are almost the only manufacturers in Lancashire who have persevered in the use of Mr. Parkes's system

of smoke burning*, which, as we have before stated, requires a greater proportion of water in the boilers than is necessary with machine firing; notwithstanding which, we have reason to believe that a degree of economy in fuel is attained by them fully equal, if not superior, to that of any similar establishment in the cotton manufacturing district. The average evaporation at all their mills being about 7 lb. of water to each pound of coal consumed, which is under 9 lb. of coal for one horse power, assuming the latter to be produced by the evaporation of a cubic foot of water;—the average for this district, as we have before shewn, being about 10 lb. per horse power.

The cause of this superiority may be principally ascribed to Mr. Elsworth's judicious arrangements for testing the evaporative powers of the boilers, which, together with frequent comparisons of the indicated power of the respective engines, has enabled him, through the experience of a long series of years, to arrive at such proportions in the construction of both engines and boilers as are proved to be the most beneficial in practice.

It ought to be a matter for congratulation amongst the manufacturers, that the spirited firm above mentioned are being the first to introduce a modification of the far famed Cornish system of working expansively into a cotton factory. They are now (1839) about to start a pair of new engines upon this principle, of the most beautiful workmanship, with cylinders of 55 inches diameter each,—and we are convinced that if it is possible to apply this celebrated mode of working to two steam engines with sufficient regularity for the spinning of cotton, it will be accomplished in this instance.

* Since the above was written, a very important paper on this subject, by Mr. Parkes, has been published, as part of the third Vol. of the Transactions of the Institution of Civil Engineers, which we may probably notice in an Appendix.

EXAMPLE OF LARGE BOILER.

110. Returning to the boiler we have in hand, we may suppose the makers of it to be anxious to have as much heating surface as possible, and therefore, contrary to the example in the last chapter, it is ordered to be placed on proper seating bricks, which only take up 4½ inches of each side of the bottom surface—leaving a clear width for the furnace and flame bed of 6 feet 3 inches; and if the bottom be arched 12 inches, the under surface will measure about 6·8 feet broad, by 17 feet long, or 115·6 square feet. Such a boiler has frequently 4½ feet depth of water, and the flues being covered-in 2 inches below the water line, gives 4⅓ feet for the height of the side surface, half of which only being effective heating surface, we have 2·166 × 34 = 73·6 for the effective heating surface of the sides. The surface at the two ends may be taken each at 3½ feet deep, by 6 feet 4 inches wide, or 3½ × 6·33 = 22·16, from which deduct ¾ of 6½, or ·75 × 6½ = 4·87 for the brick arch over the fire-door, and it leaves 17·29 for the front end, one half of which is effective, or 8·64. From the surface at the back end deduct ¾ of 4 = 3, for the take up wall, which leaves 19·166, half of it being effective, is = 9·58 square feet. These results collected are as follows:—

	Sq. Ft.
For the bottom surface......	= 115·6
Half the two sides	73·6
Half the front end	8·6
Half the back end	9·5
Total effective surface......	207·3
÷ by 9........................	23· square yards.

The above boiler has 17 × 7 = 119 square feet of water surface, and as it is supposed to have six square feet per horse power, it is equal to $119 \div 6 = 19 \cdot 83$, or nearly 20 horse power; if five square feet be allowed, then it is $119 \div 5 = 23 \cdot 8$, or nearly 24 horse power.

111. As estimating the power of a wagon boiler by the superficial extent of water surface is the customary mode in this district, and is in reality the best, when the boiler is at work and an exact measure of the heating surface cannot be obtained, we shall here give the proper formula for effecting that purpose by the slide rule:—

A	Gauge point, or sq. feet of water surface per horse power.	Width of boiler in feet.
B	Length of boiler in feet.	Horse power.

An example for the above boiler is as follows:—

A	Gauge point=6	Width 7 feet.
B	Length=17 feet.	Answer 20 horse power.

If we take five square feet per horse for the gauge point, then it is—

A	Gauge point=5	Width 7 feet.
B	Length=17 feet.	Answer 24 horse power.

My object in giving these examples is to assist in facilitating the use of the slide rule among working mechanics, many of whom have complained to me, and justly, that the usual teachers of the use of this cheapest and best of calculating machines, begin by putting them into "*dismals*," which is far too sleepy a system for men who have worked hard all day.

112. Having digressed thus far, we shall also add a formula for estimating the power of a steam engine from the diameter of the cylinder, with any given number of circular inches area per horse power:—

C	Gauge point, or circular inches area of piston per horse power.	Horse power.
D	Ditto	Diameter of Cylinder.

EXAMPLE:

C	Horse power............ 18	Gauge point=27
D	Diameter of Cylinder.. 22 in.	Ditto =27

The intelligent mechanic will perceive that he can adopt any gauge point he likes best, or obtain one by measuring the diameter of the cylinder of any engine he approves of, by the same kind of operation. Suppose, for instance, that a Boulton and Watt 40 horse engine has a cylinder of 32¼ inches in diameter, the gauge point is found as follows:—

C	Gauge point=26	Power................. =40 horses.
D	Gauge point=26	Diameter of Cylinder =32¼ inches.

113. In gauging cylinders above 40 horse power, it will be found that 25 circular inches per horse will be more near the correct proportion, and in fact it is the *exact* gauge point that ought to be used for all sizes of cylinders, and all kinds of steam engines whatever, *provided, that they have an average effective pressure of six pounds per circular inch on the piston*, the latter being supposed to move at the rate of 220 feet per minute at the same time.

An example for one of the large Preston engines before mentioned, (Art. 108,) is as follows:—

C	Horse power 120	Gauge point 25
D	Diameter of cylinder, 55 inches	Gauge point 25

Now if, instead of 220, the supposed speed, the above engine is really run at a velocity of 240 feet per minute, then we have the following proportion:—

A	As the supposed speed 220	So is the above found horse power 120.
B	Is to the real speed 240	To the real *nominal* horse power=131.

Again, if instead of the supposed pressure of six pounds, we ascertain by means of the indicator that an average effective pressure of nine pounds per circular inch is exerted thoughout the stroke; then—

A	As the supposed pressure 6	So is the last found *nominal* horse power = 131
B	Is to the real pressure... 9	To the correct *indicated* horse power = 196½.

ON THE FORM OF THE FIRE-GRATE.

114. If the boiler we are treating of had a fire-grate of 23 square feet in area, or about $\sqrt{23} = 4{\cdot}8 = 4$ feet $9\frac{1}{2}$ inches square, it would be a good proportion for 23 horse power; but boilers of this size have seldom less than 5 foot fire-bars, and the fire-grate being the full width between the side walls of the furnace, it would be $5 \times 6\frac{1}{4} = 31\frac{1}{4}$ square feet, and consequently to be in good proportion to the heating surface, it would require to be reduced nearly one-third. The easiest way of doing this is, to build up a false bridge in front of the ordinary fire-bridge, letting the bricks rest upon a cast iron plate, laid over the back end of the fire-bars. But when there is only one fire-door to the furnace, it is, generally, better to reduce the fire-grate also at the sides, (as is represented in fig. 10,) and leave it the proper square, or about 4 feet 9 inches each way.

115. This leads us to the consideration of the best form for the fire-grate of a steam-engine boiler generally, which we may assume at once to be *rectangular*, from the convenience of having all the fire-bars cast from one pattern, and the easy replacing of those which get burnt out. Excepting for this circumstance, a *circular* grate would be preferable, as in that form it would have the greatest area, under the least perimeter; for although the furnace is ordinarily sur-

rounded by bad conducting substances, yet it is impossible but some small part of the effect of the fire must be lost in that way; it must, however, be exceedingly small, even where the external brick work is exposed to the open air.

So small, indeed, is the "waste of fuel" from the above cause, that like the "saving of fuel" by smoke burning, we have never been able to discover its amount. It is astonishing how many otherwise clever men have been led away with these two fallacies, both evidently arising from the same source, namely, a prevailing disposition for the French or chemical theory of *caloric;* or, in other words, a belief that all combustible substances contain only a certain portion of caloric or heat, the whole of it being liberated when the combustible is entirely consumed.

It was some years ago calculated, by the believers in the material theory, that by the then ordinary methods of combustion, about 85 per cent. of the *whole* of the caloric was obtained; how much of the remaining 15 per cent. has been saved by the numerous improvements of late years, we are left to guess at by an inspection of the patent list. At any rate, this theory leaves very little encouragement for those who are taking much trouble to find out plans for saving fuel, more especially if, with this, we take into account a strange statement we lately met with in Dr. Ure's work on the cotton trade: it is to the effect that, in Manchester, the cost of fuel forms not more than *one* per cent. of the cost of spinning.

116. Boilers with fire-boxes, or where the furnace is contained within the flue, as in marine boilers, are, of course, not affected by the supposed waste of heat above alluded to; and, consequently, they are great favourites with some engineers. But even in these, where the furnace is nearly surrounded with water, there is an advantage in having the fire-grate as nearly square as possible; the fire being then

in a more compact space than otherwise, it is easier to make a proper disposition of the fresh fuel, so as to prevent the latter from burning irregularly or in patches, as it is very apt to do in all cases, but more particularly where the grate is much longer than wide, as in marine boilers. In some cases, where the draught is good and the fire thin, the latter always burns away very rapidly at the back end of the furnace, through which the air rushes violently, causing a peculiar roaring sound in the chimney, well known to enginemen: the draught of air being then concentrated into a *blast*, causes the flame to act something like that from a blow-pipe, and most injuriously upon the boiler; it is, however, well known to be good for *burning smoke* as well as *boiler bottoms*, for several patents have been taken out for improved smoke-burning furnaces, which essentially include this principle.

117. From the above considerations, there can be no doubt that the best form for the fire-grate is when the length and width are equal; for it is well known that a square is that form of rectangle which has the greatest area under the least perimeter. But as we wish to make this work useful to the younger portion of the operative mechanics, we shall here introduce a proof of this proposition, different to that usually given in introductory works on the differential calculus, for the purpose of showing how the same result may be obtained, by a simple inspection of the lines on a carpenter's common slide-rule.

To divide a line into two parts, so that the area of the rectangle contained by them may be the greatest possible*.

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* Let $a =$ the line, $x =$ one of the parts, and $a - x =$ the other part.

Then $x \times a - x =$ the area of the rectangle,

or, $ax - x^2 =$ a *maximum*.

Differentiating we have $adx - 2xdx = 0$;

Solution by the slide rule.—Invert the slide, and set one on C, opposite the area of any rectangle on A; say 16, for instance, as in the following example:—

A	2	3·2	4	5	8	10	16
Ɔ	8	5	4	3·2	2	1·6	1
Sums......	10	8·2	8	8·2	10	11·6	17

Here the two logarithmic lines, A and C, represent a series of numbers, which are the sides of rectangles of the same area. Now we have nothing to do but add together, mentally, any two of these numbers, beginning at 1 and 16, and reading towards the left hand, when we shall soon find, that 4 + 4, or 8 is the least sum that can be made, which is half the perimeter, and as 4 and 4 are two *adjoining* sides, the sides of the rectangle are, consequently, equal to each other: and consequently, also, equal to the square root of the area.

In like manner take any other area, which is not a square number, and by trying it, it will always be found, that when the sum of two adjoining sides of any rectangular space is the least possible, they are equal to each other.

Let the area, for example, be 30, then the operation is as follows:

A	5	5·4¾	10	15	30
Ɔ	6	5·4¾	3	2	1
Sums......	11	10·9½	13	17	31

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hence, $a\,dx = 2x\,dx$,

and dividing both sides by dx

we have $a = 2x$;

whence, $x = \frac{1}{2}a$,

or the line must be bisected. Hence, of all rectangles having the same area, the square has the least perimeter.

It may be remarked, that this solution, easy as it is, is incorrectly given in Dr. Ritchie's "Principles of the Differential and Integral Calculus," 1836.

Here we find as before, that the square root of the area $5{\cdot}4\frac{3}{4}$, is the side of the rectangle sought, as the sum of the two sides, ($10{\cdot}9\frac{1}{2}$,) or $\frac{1}{2}$ the perimeter is the least possible; of course, the whole perimeter is also the least possible.

EXAMPLE OF LARGE BOILER CONTINUED.

118. Resuming the investigation of the proportions of the boiler under consideration, (Art. 110,) we shall find the area of the end of the semi-cylindrical top to be $7^2 \div 2 = 24\frac{1}{2}$ circular feet, which × by the length 17, gives $416\frac{1}{2}$ cylindrical feet, or ($\div 27 =$) 15·425 *cylindrical* yards, or (× ·7854) = 12·11 *cubic* yards, which is steam room enough for 24 horse power.

Then for the water room, we have the depth of the water $4\frac{1}{2}$ feet, × by the width 7, which gives $31\frac{1}{2}$ square feet, from which deduct 1-6th, or $5\frac{1}{4}$ for the sectional areas of the concavities at the sides and arched bottom, and it leaves $26\frac{1}{4}$ for the area of the end of the water chamber. This × by the length of the boiler 17, gives $446\frac{1}{4}$ cubic feet, or ($\div 27 =$) 16·52, or about $16\frac{1}{2}$ cubic yards. As we have before shewn, that there ought never to be more than *ten* cubic yards of water for a *twenty* horse boiler, we have $6\frac{1}{2}$ yards too many; requiring an additional consumption of 65 per cent., upon that portion of the fuel which is used for getting up the steam every morning, or after any other stoppages of the engine.

119. Now as there is more than the necessary quantity of heating surface, we might resort to the most direct method of reducing the quantity of water, by lowering the water surface, and gathering in the brick-work of the flues a little lower down, as mentioned in the case of the small boiler in the last chapter (art. 99). But this plan is objectionable on two accounts; one is, that the *upper* part of the side surface is the *best* part of it, and nearly equal in effect to some portions of the bottom; therefore it is generally advisable not to

cover in the side flues lower down than just below the rivets of the straps which hold the upper cross stays of the boiler, as is shewn in fig. 10.

The other cause of objection is not so self-evident, although in its effects it is of a much more serious kind, and has as yet been very little attended to. As, however, the question it gives rise to, is intimately connected with the usual construction of marine boilers and the important subject of steam navigation in long voyages, we shall go into the consideration of it at some length.

POSITION OF THE HEATING SURFACE.

120. When the upper or more effective portion of the concave sides of a wagon boiler is partially covered with the brick-work, of course the flame or heated air and smoke is then compelled to act more upon the lower part of the sides, where from the inclined position of the latter, the flame being in some measure *above* the heating surface, a very feeble effect is consequently produced in generating steam; —and where under those circumstances the boiler is shorter than usual, so that flame of considerable intensity passes into the flue, it is always found that the iron in this particular part of the side surface burns away very rapidly.

The principal cause concerned in producing these injurious effects, is the well known bad conducting power of water, which renders it so extremely difficult to propagate heat through it *downwards;* but whenever the heat is sufficient in such a case to cause any steam at all to be generated at this particular part of the heating surface, such steam is then so confined, that in its egress, as it endeavours to escape upwards to the steam chamber, it is obliged to pass between the water and the internal or convex sides of the boiler, thus for a time preventing the immediate contact of the water with the heated iron plates composing the sides of the water chamber, thereby causing those plates to acquire an undue temperature and become gradually deteriorated, or, as it is called, " burnt out."

121. There cannot be the least doubt, that particular portions of injudiciously constructed boilers, very frequently become *nearly red hot*, from causes which operate similarly to the above, and consequently become so weakened as sometimes to cause the boilers to burst. And this opinion is strengthened, if not confirmed, by the fact, that there are many cases of explosions of wagon boilers recorded, in which the principal lines of fracture were nearly in a horizontal direction along each side of the lower part of the boiler, and such as would evidently be produced from the effect supposed. Such was the case in the extensively fatal explosion which occurred at Messrs. Goodier and Co.'s Callender House, near the Manchester Exchange, on the 22nd of March, 1832, at which the author was present, or at least within a few minutes of (both before and after) the time of the explosion taking place, and who took considerable pains in examining the peculiar effects produced; one of which was, that, although the two ends and all the upper part of the boiler were separated into several portions by very irregular fractures, and those portions were violently twisted and contorted in all imaginable directions, yet the bottom was completely separated from the body of the boiler by two nearly horizontal fractures, extending from end to end along each side, near the upper part of the seating plates, or just below the lower tier of cross stays. (See fig. 7.)

122. In some wagon boilers that had more than sufficient of heating surface, we have occasionally recommended that those parts which are liable to be injured from the causes above pointed out, should be covered with brick-work, and when so done, it has not been found that any sensible diminution

in evaporating power, or in economy of fuel, has been produced by it, while the saving in the durability of the boiler must be evident. Indeed it is deserving of consideration whether or not *all* those portions of the heating surface that are exposed to the *downward* action of the flame ought not, as a matter of safety, to be covered in a similar way.

The bottom plates of the inside flues, for instance, are especially liable to be speedily destroyed from this cause, which accounts for the fact that the nearly flat bottom plates of rectangular or large oval flues usually give way before the top plates, by what is called a collapse of the flue upwards, and which so much puzzled the London engineers in the case of the Victoria steamer last year, the two fatal explosions which took place in her being evidently partly produced by this cause. We have frequently had occasion to witness a partial bursting or giving way of the internal flues of boilers of factory engines in a precisely similar manner to that which caused the Victoria accidents, and where nothing but the judicious use of low, instead of high pressure steam, prevented the most dreadful consequences ensuing. As a preventive of this evil, we would strongly recommend coating the bottoms of the internal flues with Parker's or Scott's cement*, or any other bad conducting substance of a like nature, a practice which has been recently introduced

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* The "Anti-corrosive Iron Cement" is a peculiar composition now much used for steam-pipe joints, and all the other purposes for which the ordinary iron cement is applicable. It is manufactured by Mr. John Scott, of Monkwearmouth, Durham. It has been long used with great success in the form of a thick paint for preventing what are termed blows or leaks in high pressure boilers; it has the property of hardening under water, and when once hard, no art can soften it again; and it is much preferable to the Roman cement, for the purpose stated. It is sold in Lancashire by Malilieu and Lees, ironmongers, Manchester.

with great success, by Mr. Dinnen, in some of the government steam vessels; for an account of which see his paper in the appendix to Tredgold.

123. The fact of the inclined sides of boilers over which the flame may occasionally pass, soon becoming *burnt out*, is so well known to boiler makers, as well as to the more observant of the owners of boilers, as to induce a suspicion with some, that the effect of the action of the fire against any portion of the heating surface in producing steam, is nearly in an inverse ratio to its effect in burning away the iron. Without agreeing to this in its fullest extent, it may be stated, that facts are sometimes adduced which add not a little to the plausibility of the hypothesis. One of the most common is, that, if we heap live coals *upon the top only* of a boiler, we may urge the fire as much as we please, but it will be a *very* long time before the water is made to boil, although we may very soon burn a hole in the boiler.

There are, besides, many other equally well-known facts to this effect, and which are usually adduced as illustrative of the very slow conducting power of water for heat. So very slowly, indeed, does water conduct heat, that the celebrated Count Rumford held the opinion that it was a perfect non-conductor; this opinion, however, was proved to be erroneous by some well conducted and decisive experiments of Dr. Dalton's, in 1799*.

124. Although water is so very bad a conductor of heat in the manner of solids, or from particle to particle;—it is, however, well known to be an excellent *carrier* of heat; that is, each particle of the fluid, as soon as its temperature

* Vide Manchester "Memoirs," Vol. V. Pt. 2.

becomes elevated by contact with the heating material, suddenly rises to the surface of the water, and is there dispersed in vapour. The velocity of each heated particle of course increases with the increased temperature of the heating surface, until ebullition commences,—at which time the formation of steam also commences at the bottom of the boiler,—and then the velocity of the heated particles upwards is the greatest possible. At this period of the process, the heat is the most rapidly abstracted from the heating surface; and when the bubbles of steam rise *perpendicularly from that surface*, the position of things is then evidently such as to conduce the most favourably for the cooler particles of water rapidly and successively taking the places of the heated ones, as the latter are driven off in the shape of steam; thus tending to keep the metal of the boiler bottom (or any other *horizontal* portion of the heating surface) cool, or at most not hotter than the water itself when boiling.

125. There is a certain paradoxical experiment, probably familiar to most persons, which may be mentioned here, as being in some measure illustrative of the tendency of boiling water to keep the bottom at a lower temperature than any other portion of the boiler that is equally exposed to the fire; and also because the peculiar phenomena involved in it, have not, that we are aware of, yet received any adequate explanation, or that they admit of any, except upon the principle of *longitudinal conduction;* a subject of which we are about to treat in the next section.

The experiment alluded to is, after causing water to boil briskly in a common tea-kettle which has some considerable substance of metal, and while it is yet boiling, to take the latter from the fire and place it immediately upon the naked hand, where it may be retained with impunity for several seconds, or so long as the water continues to boil, the bottom of the kettle, during the time, not being at higher temperature than that of blood heat, while the sides and top, and sometimes the handle as well, (as is well known,) will be too hot to admit of being touched; the sides in particular being considerably above the boiling point, and to which the temperature of the bottom very soon approaches after ebullition ceases, but not until then.

ON MARINE BOILERS.

126. The *extent* of the *heating surface* in boilers, like the extent of the *cooling* surface in condensers, has engrossed so much of the attention of patentees and engineers for several years, that it seems to have had the injurious effect of preventing sufficient attention being paid to other matters equally important; and amongst the most important of those things that appear to have been thus unaccountably overlooked, is the *position* of the heating surface, the effects of which we have endeavoured to illustrate in the preceding articles. To marine boilers, which have the greatest portion of their heating surface, in general, vertical, the above remarks have especial reference. The very rapid destruction of those boilers, particularly in the *sides* of the furnaces, is a matter of notoriety, and we are convinced that a great portion of it is owing to the cause we have stated above, which opinion has just received a farther confirmation by the recently published experience of Mr. J. Dinnen, assistant-engineer in H. M. Dock-yard, Woolwich*.

127. From the above-named gentleman's paper, which is one of singular excellence in all that relates to the practical details of this most essentially practical subject, we gather, that he is almost inclined to despair of thoroughly obviating

* Published as an appendix to the second edition of Tredgold on the Steam Engine. Weale, London, 1838,

the evils to which marine boilers are subject in very long voyages, unless by having recourse to either distilled water, or copper boilers, or to both. But that there is no absolute necessity for resorting, in all cases, to either of those very expensive, although generally acknowledged efficient remedies, it might *now* be considered sufficient proof to point to the Great Western and the Royal William steam-ships, both of them having performed several transatlantic voyages with iron boilers, in the most successful manner; and in both cases, we are assured, without the slightest injury being sustained from deposit or incrustation.

This triumphant result, in the instance of the first named vessel, is to be ascribed principally to an ingeniously arranged plan of Mr. Field's, for continually drawing off a portion of the salt water, by means of what are called change-water-pumps, and without the loss of heat; combined with an apparently highly judicious system of management. In the other vessel, the attainment of the same result may be fairly attributed to the peculiar form of the furnaces and flues; and the consequent position of the heating surfaces, which compose those portions of the boilers; although accompanied with nothing more than the common system of occasionally blowing out the boilers in the ordinary way.

On the other hand, the Sirius steam-ship, although provided with Mr. Samuel Hall's patent condensers for supplying the boilers with distilled water, did not venture upon a *second* transatlantic voyage. This fact is not stated here with any view of in the least depreciating the distilled water system, as a means of keeping the boilers free from incrustation,—its efficacy in that respect, of course, being indisputable; but it would appear that the very small advantage that can be obtained by it, over the plan of Mr. Field for effecting the same purpose, or even over the ordinary system of blowing out, is at most not yet proved to be worth the expense; whatever may be expected to be proved in the case of the British Queen, which vessel is understood to be preparing to work upon Hall's system *.

128. Independent of the above practical argument, there are also sufficient reasons for coming to similar conclusions in respect of *copper boilers*, if we examine a few of the facts brought forward by Mr. Dinnen; who, after stating his fears "that nothing but the use of distilled water will ever thoroughly obviate the evils to which marine boilers are subject on very long voyages, although at the end of *five or six years in active employ a copper boiler may not be liable to injury*, if properly attended to; while it is notorious that the *fireplaces* of *iron* boilers of similar construction employed between Falmouth and Corfu, *require repair almost at the conclusion of every voyage*." He adds that "the African (government steamer, with copper boilers) was three years employed before it was deemed necessary to detach the scales." Further on, however, it appears that "in the sixth year the vessel being actively employed in the Mediterranean, the boilers were scaled about once in three months, the number of entire days at sea in that time being sixty or seventy." (See page 9 of Tredgold's Appendix.) In another place,

* As a specimen of the extravagant expectations of some of our northern neighbours respecting this vessel, we may quote the following passage from a review in Tait's Edinburgh Magazine for October, 1838, of a recently published popular little work on the steam engine by Mr. Hugo Reid.

"One superb example of a grand engine is about to be placed by Mr. Robert Napier in the BRITISH QUEEN. May the gods be propitious! Mr. Napier will succeed, if mechanist now can, and there is no hazard, except in relation to the strength of the castings. *He will succeed*—and we do not despair that before he closes his grand terrestrial vocation of making steam engines, he will have furnished a ship for the Australian trade in length *at least a quarter of a mile!*"

(page 17,) Mr. Dinnen informs us that "*the crowns of the furnaces, whether of iron or copper, never decay*, and rarely alter their figure, if arched, unless the water is allowed to descend below them."

Now a very little consideration of the above facts, together with those before mentioned, relating to land boilers, will be found to be quite sufficient to account for the very great disproportion (under ordinary circumstances) in the durability of copper boilers over those of iron.

129. There can scarcely be a doubt in the mind of any practical man, who is not predetermined to attribute every thing he does not understand to some mysterious chemical agency, rather than seek its cause in any common sense explanation of plain matters of fact, that the principal cause of the premature destruction of marine boilers, whether of iron or copper, (independently of that arising from deposits,) must be looked for in the imperfect access of the water to the nearly vertical sides of the furnaces and flues owing to the partial interposition of the rising bubbles of steam as in the nearly analogous case of land boilers (art. 120). And more particularly if to this be added the probability of the steam being frequently partially confined or "locked" by various little projections in the water ways, such as the straps to which the stays are bolted, or by injudiciously placed seams of rivets.

That boilers made of copper are not subject to have the sides of their furnaces burnt out so rapidly as those of iron, setting aside the acknowledged advantage possessed by the former metal, owing to its peculiar constitution or manufacture, arises principally, if not solely, to its superior conducting power over iron, it being nearly as *three* to *one*. Heat being in both cases conducted *longitudinally upwards*, through the body of the metal of the vertical side plates of the furnace, to the crown or horizontal portion of the top of the furnace flue, where, from the circumstances stated in the last section, (art. 124,) this heat is the most rapidly abstracted by the water. Although this *longitudinal conduction* of the heat is, of course, carried on by iron in precisely the same manner as by copper, yet it is to a much less amount or degree in the same time;—hence heat must be frequently unduly accumulated in the side plates of the iron furnace, and the increased temperature thus acquired by the metal, of course produces its natural consequence, an increased formation or incrustation of sulphate of lime* in the water ways, which again reacts as a producing cause for still greater accumulations of deposit, by preventing the contact of the water with the iron, this again tending to raise the temperature of the metal still higher, and thus the evil goes on reproducing itself in a rapidly accelerated ratio, until at last the plates "give out;" and then, owing to the laminated structure of the iron, the mischief is soon evidenced by *blisters* and cracks, denoting permanent injury, and rendering the immediate removal of the burnt plates inevitable.

130. In land boilers with fire boxes, it is uniformly found, that a thin fire, and the coal uniformly supplied by the firing machine, is highly conducive to the preservation of the metal sides of the furnace, besides being much more efficacious in producing steam and economy of fuel, provided

* Of the fact of the incrustation of *sulphate of lime* being greatly promoted by an increased temperature of the plates, we have had the most satisfactory evidence, although a thorough understanding of the exact *modus operandi* seems yet to be wanting amongst engineers. It has been suggested as probable, that the decomposition of the ordinary deposits of carbonate of lime is assisted by contact with the overheated plates where the sulphate is *gradually* formed, as the sulphuric acid which may be present gradually acquires a sufficient degree of concentration for that purpose.

that the fire grate is elevated proportionately nearer to the boiler bottom; which latter condition would appear to involve a paradox, as the heating surface adjacent to the fire is thereby actually diminished, but for the solution which the above theory of longitudinal conduction affords us.

Some comparatively coincident facts in relation to this matter have been observed by Mr. Dinnen, who has lately informed us that it has been found in some marine boilers, that raising the far end of the grate bars, has not only been attended with greater economy of fuel, but the sides are found to sustain less injury in the same time, the latter effect of course being attributable to there being a less depth of the side plates of the furnace presented to the burning fuel, and therefore a less amount of heat required to be carried off by longitudinal conduction upwards.

THEORY OF LONGITUDINAL CONDUCTION.

131. Now as to the amount or proportion of the heat conducted upwards from the side plates to the crown, in an iron boiler as compared to one of copper, those who have attended to the cooling of metals by contact will perceive that it must be very considerably less than we might expect from the numbers expressing the simple ratio of the conducting powers of the two metals.

To render this more evident, it is necessary, in the first place, to consider that the temperature of the metal of the crown plates of the furnace, considered separately from the sides, must have a tendency to rise in a ratio inversely proportional to the rapidity with which the heat is transferred through the plates to the water, or *inversely as the conducting power of the metal of which they are composed.* In the next place, we know that the heat from the burning fuel in immediate contact with the lower part of the side plates (always excepting such portion of it as may be transferred laterally to the water between the furnaces) must be conducted longitudinally upwards by the metal of the side plates to that of the crown, *in the ratio of some power of the difference of temperature between the crown and the sides,*—the temperature of the latter having a tendency to rise *inversely in this ratio.* Consequently the total effect of the undue action of the fire against the side plates of the furnace must be as the above two ratios conjointly.

132. In illustration of the above reasoning, we may suppose that the excess of temperature superinduced by the undue action of the fire upon the metal, is *exactly* inversely as its conducting power; while the transmission of heat from the sides to the crown is *exactly* as the square of the same; then, the total effect upon the sides will be *inversely as the cube of the conducting power of the metal.* For example; if the conducting power of copper be to that of iron as 3 to 1, then the undue action of the fire against the side plates, when of the latter metal, as compared to those of the former, will be as $3^3 : 1$, or as 27 to 1, and the durability of the copper over the iron would be in that proportion.

The proportions used in this example are not given even as approximations to those they are meant to represent, for it is believed that their actual values are such as would give a much lower result, but which have not yet been sufficiently determined by experiment; and they are only used here for the purpose of giving a more popular view of our general theory of the manner in which the sides of an iron steam-engine furnace are so excessively acted on as compared to those of a copper one.

133. If an algebraical expression for the above theory be preferred, it is as follows :—

$$\frac{1}{M} \times \frac{1}{(T-t)^n}$$

where M represents the conducting power of the metal for heat, T = the mean temperature of the side plates of the furnace, t = that of the crown plates, and ^{n} = the index of some power of $T-t$, expressing the rate of cooling of a hot metal plate, with its edge in contact with one of a lower temperature, to be determined by experiment.

Now if the above be a correct expression for the total action of the fire against the sides of the furnace, of course its reciprocal will furnish us with an equation for the relative durability (d) of the side plates of iron, copper, or any other material that may be used in the construction of the furnaces of marine boilers of the usual form, that is,

$$\frac{1}{\frac{1}{M}\times\frac{1}{(T-t)^n}}=d,$$

or.....................$d=M(T-t)^n$.

Substituting the nominal proportions stated, namely $M=3$, and $(T-t)^n=3^2$, then $d=3^3=27$, as before. This result, as it happens, is not very far from the truth as regards the fire boxes of locomotive engines, which may be taken as a good criterion in an investigation of this nature, they being free from those adventitious circumstances which are supposed to affect marine boilers.

134. The circumstances alluded to are, of course, those relating to the variable nature of the encrusted deposits formed within the boiler, from which locomotives under ordinary management are entirely free. The peculiar effect of the coke upon the copper *tubes* formerly used in locomotive boilers, was produced almost entirely by the mechanical action or friction of the small particles of coke in their rapid passage through the tubes caused by the intensity of the blast, and is now completely obviated by Mr. Fife's admirable substitution of *brass* instead of copper. This mechani-

cal action, which proved so destructive in wearing out the copper tubes, does not, however, except perhaps in a very slight degree, affect the copper fire box itself, although there is reason to believe that the common gas coke which usually contains a portion of sulphur, has an injurious effect, but this kind of coke, which a misjudged economy alone tolerated, is now entirely disused upon all well managed railways.

135. As the numbers used in the example in article 133, are so entirely empirical, it may be satisfactory to examine the conditions of the problem with more accurate data. The conducting power of copper, in proportion to that of iron, is, according to the experiments of Depretz, quoted by Dr. Lardner in his treatise on heat, as 89·82 to 37·41, or as 2·4 to 1. We may assume that the temperature of the metal of the crown plates, when of copper, is not perceptibly greater than that of the water above it, which for low pressure steam from fresh water we may call 215° Fah., or $t=215$; and the temperature for iron will be one or two degrees higher, according to the thickness of the metal and other circumstances. We may also make T four or five degrees higher than t, say 220°, or any other temperature which the copper may be able to bear without material injury, on the supposition that only a certain limited and small amount of heat passes through the side plates laterally to the water. When the sides of the furnace are of iron, their temperature will of course be the same as for copper, they being equally exposed to the contact of the burning fuel on the grate, provided that nearly all the heat derived in that way is carried off by longitudinal conduction, in the same manner, although at different rates, by both metals; or, which amounts to the same thing in this investigation, on the supposition that the quantity of heat transmitted laterally is equal in each case.

136. According to the above we shall have—

For copper . . . . $d = 2{\cdot}4\,(220-215)^n = 2{\cdot}4\,(5)^n$

$$\text{For iron}\begin{cases} d = (220 - 216)^n = 4^n \\ d = (220 - 217)^n = 3^n \\ d = (220 - 218)^n = 2^n \end{cases}$$

accordingly as we assume the value of t for iron.

Then if we make $n = 2$ we have $2{\cdot}4 \times 5^2 = 2{\cdot}4 \times 25 = 60$ for the relative durability of copper; and for the relative durability

$$\text{of iron}\begin{cases} 4^2 = 16 \text{ which is to 60 as } 1 : 3{\cdot}75 \\ 3^2 = 9 \quad . \quad . \quad . \quad 1 : 6{\cdot}6 \\ 2^2 = 4 \quad . \quad . \quad . \quad 1 : 15 \end{cases}$$

137. Now as the highest of these calculated results (15 to 1) is considerably less than the average result found in practice, it would appear that the transmission of heat from the side plates to the crown, increases in a higher rate than as the square of the difference of temperature, which is hardly probable; otherwise we must fix the value of T a little lower, say at 219° instead of 220°, and in that case the value of d for copper will be

$$2{\cdot}4 \times (219 - 215)^2 = 2{\cdot}4 \times 16 = 38{\cdot}4$$

And for iron:

$(219 - 216)^2 = 9$, which is to 38·4, as 1 : 4·26
$(219 - 217)^2 = 4$, . . . as 1 : 9·6
$(219 - 218)^2 = 1$, . . . as 1 : 38·4

138. In marine boilers, the average temperature of clean salt water under a pressure of two to three pounds on the square inch is 222°, and supposing the difference of temperature between the sides and the crown to be the same as before, namely 4°, the result as stated above will still follow exactly; the formula in that case being expressed by
$d = 2{\cdot}4\,(226 - 222)^2 = 2{\cdot}4\,(4)^2 = 38{\cdot}4$ for copper as before.

It ought to be stated that, from the circumstance of certain boilers producing steam very rapidly, which are almost entirely composed of side surface, (amongst which we may mention the boilers of Hancock's steam carriages, also those of Chanter and Co.'s patent, and for marine purposes, Collier's patent boilers,) it is probable that the ratio of transmission upwards should be assumed rather *under* the square of the difference of temperature as already surmised (art. 137); this, in fact, being quite hypothetical, and only suggested by the remote analogy of water flowing through a pipe communicating with two cisterns under different heads of pressure.

Therefore, in the absence of direct experiment, we may suppose $n = 1\frac{3}{4}$ instead of 2; then will

$$d = M\,(T - t)^{\frac{7}{4}}$$

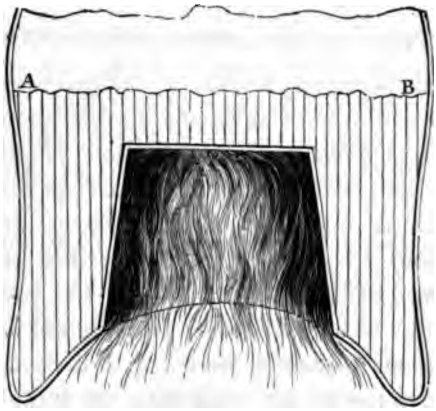
which will give 27·12 for copper.

Hence, if the above law of conduction is correct, we see what a great effect is produced by a very small difference in the conducting power of the metal. For we have only to suppose the crown of the furnace of an iron marine boiler to acquire a temperature of no more than 3 degrees higher than that of a copper, and the sides of each to be only one degree higher than that temperature, to make a difference in durability in favour of the copper boiler in the proportion of 27 to one.

139. The most obvious remedy for the evil effects produced in iron boilers, which we have described above, is either to have as little side or vertical surface, and as much horizontal heating surface as possible; or otherwise, so to construct the furnaces and such of the flues as are likely to be much acted on by the fire and flame, that they may be a little narrower at the top or crown of the flue than lower down, thus causing a slight inclination of the side surface toward the fire, and consequently allowing the steam to escape freely from the heating surface. The best example of this construction is perhaps in the ordinary land boilers of

Boulton and Watt, particularly in that part of the inside flue called the uptake, a section of which is shewn in the annexed cut, where A B is the level of the surface of the water, and

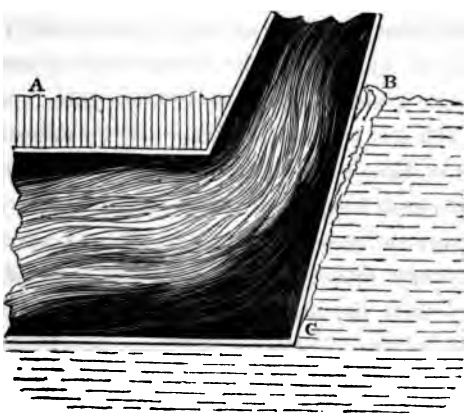
Fig. 8.



the vertical parallel lines, shew the direction taken by the rising bubbles of steam as they ascend from the heating surface.

A striking contrast to this is shewn in the ordinary uptake of a marine boiler, where the position of the heating surface is exactly the reverse of the above, as at B C in the following figure, the heating surface *declining from*, instead of *in-*

Fig. 9.



clining towards the fire, consequently the steam as it rises from that portion of the flue, effectually prevents the proper access of the water to the heated metal, and consequently that part of the flue is usually found to decay very rapidly.

EFFECT OF CALCAREOUS INCRUSTATIONS.

140. It has been long known to operative engineers and boiler makers, who have sufficient knowledge of their business not to be led astray by the plausible representations of interested patentees and quack speculators in new inventions, that so far as the durability of the sides of the furnaces is concerned, and it is only in that respect that any advantage can be claimed even for copper boilers, the adoption either of the latter or of any system of cleaning out or of preventing incrustation, instead of attending to the proper form and construction of the furnaces and flues, are at the best but palliations of the evils they are intended to remedy. The formation and induration of thick scales of sulphate of lime being, as we have before shewn, (Art. 129,) quite as much a *consequence* as a *cause* of the overheating of the side plates of the flues.

141. The precipitation of *carbonate of lime* in boilers, of course goes on more or less at all temperatures, and this substance is indifferently disposed to deposit itself upon all the parts immersed, particularly at those times when the water is comparatively still; but whenever the water boils, the deposit is driven away from, or rather prevented settling upon those parts of the heating surface where the ebullition is the most violent, and where the steam is principally generated. Hence, wherever this deposit is found to accumulate, it always indicates either a deficient circulation of the water, or a diminished production of steam in those particular parts of the boiler. This is a well ascertained fact, and on this principle was founded Mr. Anthony Scott's patent me-

thod of preventing deposits by collecting them into various receptacles properly placed within the boiler.

142. With respect to the *sulphate* of lime, it acts rather differently to the carbonate, and attaches itself firmly to the *hottest parts* of the boiler, apparently independently of the circulation, and as we have already observed, is probably formed subsequently to the deposition of the latter. It is also found to have a great tendency to adhere in stalactites to the rivet heads and other projections from the vertical sides of the flues, while on the crown it merely forms a thin skin, which is found to be rather beneficial than otherwise, more particularly in the case of copper boilers.

That the sulphate of lime forms only upon those portions of the boiler that are unduly heated, admits of being easily proved by experiment. We have watched the progress of its formation, from week end to week end, in several land boilers, and have also frequently found boilers to work for years without the least trace of the sulphate of lime; but when it has happened that, from some circumstance or other, the fires have required to be pushed, or the draught has been improved, the formation of this kind of incrustation has immediately commenced, although the water used continued to be identically the same as before. This effect of the increased heat is proved by the *gradual induration* of the *carbonate*, and eventual production of the *sulphate*, at first only upon those parts where the fire acts with the greatest intensity. It is this incrustation of sulphate of lime which adheres to the iron with so much tenacity, and which occasions so much trouble in its removal; that consisting of the carbonate of lime being more easily scraped off, or prevented from accumulating to any injurious extent by other means, which we shall point out in another chapter.

143. Several facts corroborative of the principal points

dwelt on in the above views appear to have been frequently met with during the experience of Mr. Dinnen, in the "African" steamer before alluded to. It appears that this vessel was employed for several years principally in the Mediterranean and on the Lisbon service, during which time the boilers "were not in any way submitted to the operation of cleaning out till the expiration of the third year; a very slight scale was then removed, leaving the surface scaled precisely as when rolled." This is a remarkable result, although strictly in accordance with our own experience with land boilers; and we quote it with the more pleasure as coming from a gentleman apparently imbued with a conviction of the necessity of attending to practical rather than theoretical considerations in all attempts to improve steam machinery. Indeed the whole of Mr. Dinnen's paper is highly deserving the most attentive consideration of every one connected with steam navigation; while it is not a little curious as a contrast to the general speculative character of Tredgold's work, to which it is appended; besides shewing a rare instance of any one connected with government, and we might almost add, with any large public company, discarding the trammels of science, falsely so called, which would set bounds to the progress of invention and improvement by too frequently impeding, or counting too lightly, the communication of results of a practical nature.

ON REDUCING THE QUANTITY OF WATER IN ORDER TO SAVE FUEL.

144. The plan which the most readily suggests itself for diminishing the quantity of water in land boilers, without diminishing its depth, or lowering the water surface, is that of putting an iron flue through the lower part of the boiler, and this is the most usual course recommended by boiler makers, as it gives an additional quantity of heating

surface; but when, as is the case with the large boiler, which is the subject of this chapter, the latter is not needed, the putting in of a flue is hardly advisable, because it is attended with a great deal more trouble, and in the end is not much less expense than replacing the boiler with a new one, made with good proportions.

There are many cases, however, such as where the property is held on a short lease, or from other circumstances, in which it may be desirable to avoid all alterations of an expensive character, and where some cheap plan must be adopted, if any. In those cases, the plan of placing filling-up blocks, or large pieces of any solid substance, such as iron, stone, wood, or any other material that is of sufficient bulk to be capable of displacing the surplus water, may be adopted with advantage. The articles used should be fixed upon a sort of platform, laid upon the internal stays of the boiler, and in such a manner as to be sufficiently clear of the bottom and sides of the water chamber, something like that represented in Figs. 10 and 11, page 126.

When we first recommended the above plan of filling-up blocks, for the purpose of saving fuel, it was immediately adopted at several large works, in various parts of the North of England. Nothing can be more simple and cheap, for it may literally be said to cost nothing, as almost any thing may be used that comes to hand; therefore we may easily suppose that it was frequently adopted without judgment or discrimination, and occasionally did more harm than good. In one case, where a quantity of timber was put into the boiler for this purpose, we were informed that it had the effect of preventing incrustation. Hollow water-tight vessels, like the portable-gas receivers, have also been proposed for this purpose; a modification of which was also proposed to the Directors of the Liverpool and Manchester Railway, as a means of regulating the height of the water in the locomotives, independently of the action of the force-pumps, but which the subsequent invention of the multiflue boiler, by Mr. Booth, rendered inapplicable.

145. The late Mr. ~~Robert~~ George Stephenson, so well known for his various inventions in steam and railway engineering, was so convinced of the necessity of generally diminishing the capacity of the water chamber, and also of the inutility of using internal flues as heating surface, that he had some large boilers made with what he called "blank flues," that is, with one end of the flue stopped up, so as to prevent the fire from passing through. These flues, or rather tubes, were principally intended for the purpose of displacing the water; but certainly the best, as well as the cheapest way of doing this, is to have solid slabs, or blocks of stone or brick, built into a sort of rough wall, upon iron bars resting upon the lower tier of stays, and leaving plenty of room all round for cleaning or repairing the boiler.

When this plan is used with judgment, a considerable saving of fuel is the never-failing result. And it is also possible that these filling-up blocks may have a beneficial effect in respect of the evaporating power of the boiler, independently of the effect arising from the displacement of the water, and which may be likened to that of the fly wheel on the engine, by becoming a sort of reservoir of power, or *regulator* to the evaporating power of the boiler. This effect is especially observable when compared to the irregular action of a boiler with an inside flue, and fired by hand, the steam being liable to vary very considerably in the latter every time the furnace door is opened to supply fresh fuel.

EXPERIMENTS WITH SEDIMENT COLLECTORS.

146. We were first impressed with the importance of attending to the above particulars, some years ago, when

engaged in trying what amount of saving of fuel was to be obtained by using Mr. Anthony Scott's patent method of preventing boilers becoming foul, which was alleged by him to be ten per cent. This plan, which we shall afterwards have occasion to refer to, was, to place within the water of the boiler a number of vessels, of various kinds, chiefly earthen pots, for collecting the sediment, and usually as many as occupied from one third to one half of the water space. At the request of the patentee, we had his invention put to the severest tests, and for that purpose had the sediment collectors placed in a great number of boilers, and the results, on an average, fully bore out his statements. But on tabulating those results, for the purpose of making out a report of six months' experiments, a great discrepancy was observed in the proportion of saving at different boilers, although two of them, at which a great difference was found, were using the same kind of water, and alternately working the same engine; in fact, while the saving at one boiler was only 5 to 6 per cent., that at the other was about 12. The cause was immediately evident, for the first-mentioned boiler had a flue inside, which occupied a considerable portion of the water room, and had been previously rather the most economical of the two, but the collectors turned the advantage in favour of the other. To set the matter beyond dispute, the collectors were placed in several boilers in which the water was quite pure and clean, and always with a similar result as to saving fuel, although not to so great an amount. Wherever the pots were used, the steam was uniformly sooner got up, and with less fuel; in this, the effect resembled that of a flue boiler, but, unlike what is usually observed in the latter, the steam was not so soon down again, and was consequently more steady and easy to manage.

Notwithstanding the above evident advantages, the pots have fallen a good deal into disuse, partly from the trouble they give the workmen in occasionally emptying them, and partly because other methods of keeping the boilers clean have been since invented.

147. In speaking of what have been called "vested interests," (existing patents,) it is perhaps always necessary to guard against being misunderstood, as one reviewer at least construed the above paragraph, as printed in the first edition of this work, into a "very decidedly unfavourable opinion" of Mr. Scott's patent collectors, but which, as will now be seen, is very far from being the case. It is certainly true, that the *earthen* collectors or *pots* have been in a great measure superseded by a different mode of application to that at first recommended by the patentee, but the principle of the invention has been in no way departed from. This explanation is in justice due to Mr. Scott, as his invention has been the germ of several other contrivances, either for effecting the same object, or in some way connected with the improvement of the steam-engine boiler.

Although the above apparatus has now been improved into a very different looking thing to what it was when first introduced, yet it was then a very great improvement in the economy of the steam-engine, and it is still very extensively used in its original state. We have reason to believe that it is so used in many hundreds of boilers without the patentee receiving any remuneration whatever for it; which is owing in a great measure to the cheapness and simplicity of the apparatus, and the ease with which a knowledge of its being used can be prevented transpiring, and therefore payment evaded, it being entirely confined within the boiler, and consequently out of sight. We know several instances, both in Lancashire and Yorkshire, where other patents as well as this are constantly infringed under similar circumstances. In Manchester we know one singular individual who used the patent collectors in his boilers a number of years, and always refused to pay, on the ground of their simplicity and cheapness, arguing that a patent for an apparatus could not be good when the latter had no appearance of ingenuity or machinery about it; or, to use his own words, "there was nothing *scientific* about it, it was so obvious, that *any one might have thought of it*, and *therefore* he had a right to use it without paying for it, and advised others to do the same." Now, it is a fact, that after the proprietors of this patent at great labour, study, and expense, succeeded in improving the apparatus, so as to make it in some measure self-acting, or, as Dr. Ure calls it, "*automatic*," and consequently more like a machine, although more complicated, the very same gentleman (who by the by is not an Englishman) immediately adopted those improvements, but still refused to acknowledge the right of the inventor to recompense, on the legal ground, as he said, and he is a great authority in these matters, that the improvement invalidated the original patent.

148. On the principle that example is better than precept, perhaps in law as well as in mechanics, we have considered that the above digression may have its use as a warning to those who have too much faith in the protection afforded by patents. Owing to our present infamous patent laws, most useful inventions are over-ridden and borne down by a host of imitators, and patent plagiarists, who, like other copyists, mostly copy best the worst parts of the picture, and who have done more perhaps to check the progress of improvement than all other causes put together, by a system of legalised robbery upon every inventor who may be induced to attempt in this way to reap a reward for his ingenuity and industry. Second only to this cause in discouraging invention, is the occasional conduct of that portion of the periodical press usually devoted to record the progress of science. While the editors of some of those works confine their lucubrations to scientific and literary matters alone, they are in their proper sphere; but all attempts to influence

public opinion respecting new inventions in the multifarious operations of practical mechanics by writers who, although calling themselves *practical* men, never perhaps handled a work tool of any kind in their lives, save a *pen* or a *pair of scissors*, must, to say the least, be as injurious to the much cried up interests of science as they manifestly are to those of honest industry.

We acknowledge that the above remarks admit of numerous exceptions in their application; but notwithstanding those exceptions, and however respectable a critic's attainments may be in mechanical and chemical operations, as well as in literary and scientific knowledge, an unavoidable barrier must necessarily exist against the willing reception of new truths, in the minds of all those who are expected to write or say something upon subjects with which they may have a reputation of being familiar. Indeed, the higher the critic's scientific attainments, under such circumstances, the more insuperable in general are his prejudices, and the more impervious he is to the conviction that there can be any "new thing under the sun." This feeling perhaps in some measure arises from the very nature of new inventions, they being essentially the discovery of new facts, or *facts not previously turned to any useful account by others;* consequently all new discoveries in the arts and sciences are, in reality, discoveries of the ignorance of others, and have generally a tendency to discompose, in the minds of some individuals, the previous orderly mental arrangement of the subjects to which they relate; such tendency being apparently the most sensibly felt in minds of the highest order in scientific research. Hence it is that we have frequently found amongst the would be aristocracy of science, the greatest enemies of the uneducated mechanic, whenever it has been the luck of the latter to hit upon a new invention or make a new application of an old one.

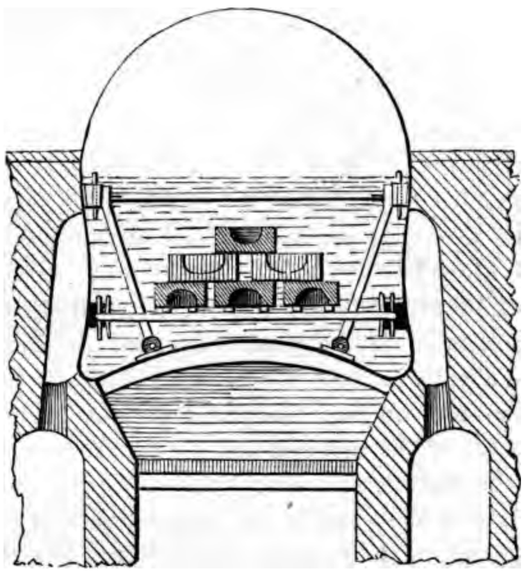
ON CHECKING CIRCULATION.

149. There are two very evident and important conclusions to be drawn from the experiments with the pots; one is, that *an inside flue is of no use in a boiler*, provided that the quantity of water is not greater than a certain proportion easily determinable, and that the area of heating surface is sufficient for the evaporation required: the other is, that the heat expended in giving *circulation* to a large body of water in a boiler, is so much heat wasted; consequently, *all arrangements in the construction of a boiler for the purpose of promoting a more rapid circulation of the water, as a mass, must have a tendency to waste fuel.* To understand how this follows from the above experiments, we must bear in mind, that in using the pots, or other sediment vessels, the quantity of water in the boiler was not so very much less than ordinary, and, at any rate, not more than the cubic space occupied by the materials of which the vessels were made, and they were made sometimes of thin sheet iron or tin plate, which is practically of no account; therefore, the effect stated is evidently due to the keeping out of circulation the large portion of the water contained in the internal vessels, the water in those vessels being of course always in a quiescent state, on the principle of the water bath, or *balneum maris*, of the older chemists, an arrangement which those of Boerhaave's time, considered would only convey one half the heat of the water in the external bath or boiler, to that contained in the internal vessel; but in this, they said more than they knew to be true; the only material fact is, that the water contained within the inner vessel never boils, however violently it may boil externally.

150. The best confirmation of the truth of the above theory of circulation is that the vessels themselves generally had the effect of breaking or interrupting the circulation of

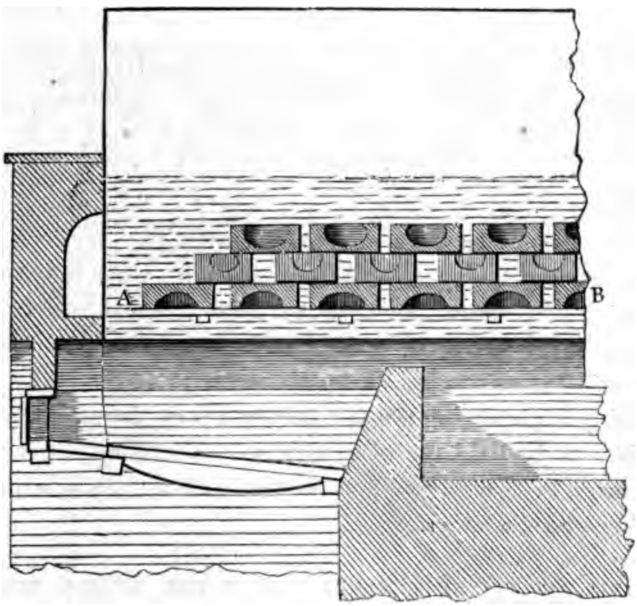
the water; and this effect was considerably increased by placing them in different positions, transversely across the boiler, when it was always found that they caused a proportionally greater saving in fuel, besides in some measure being a preventive of priming. For effecting the last mentioned object alone they are still occasionally used, but they are placed in the boilers in an inverted position, and require to be kept down by weights or other means; for this object, however, another form of vessel is preferred, as shown in figs. 10 and 11.

Fig. 10.



These vessels or rather blocks made with a concavity on the under side, and placed, as represented by the lower row of articles A B, in fig. 11, and also in transverse section in fig. 10, are made of fire brick, of such a size as is just sufficient to go through the man-hole of the boiler, and as heavy as a man can lift; they are placed upon each other in the manner represented in the figures, with small spaces left between them. This arrangement of vessels, or blocks, completely answers the purpose of preventing priming, unless the water is very dirty; but when they are arranged longitudinally in rows, or in the direction in which the water *circulates*, the priming is thereby accelerated, as well as the circulation. These articles received the name of *generators* from their apparent use in assisting the generation of steam; this appearance is very striking when a model of the apparatus is seen at work in a small glass boiler.

Fig. 11.



The apparatus was first publicly exhibited in that way in Manchester, at the time of the opening of the Liverpool and Manchester Railway, and was witnessed by thousands of persons; there being no patent for it, of course it was extensively adopted at the time; but, like all new things, the principle of it was liable to be carried too far by many persons, especially by those who hold the opinion that there cannot be too little water in a boiler, provided that all the heating surface is covered; which caused the water chambers of the boilers to be sometimes nearly filled with the fire-brick generators, leaving only a small space or *shell* of water between them and the sides of the boiler; the consequence of which was, that the apparatus would keep up the steam for some time after the fire was put out—a fact decisive of its economy in a theoretical point of view; yet, owing to the waste of water, caused by the steam blowing away at the safety-valve during the night or after the engine had stopped, the generators were found to be troublesome in practice, which has in a great measure caused their disuse.

151. In consequence of the practical disadvantages of the nearly solid generators, we have since recommended large vessels made of thin sheet iron, like gas holders, to be immersed in the water of the boilers in an inverted position, or mouth downwards, as in fig. 12, p. 129. Now when a generator is made in this way, there is, of course, very little displacement of the water until the steam is up, when it becomes filled with steam, which forces the water out, and in that way it becomes a positive addition to the steam chamber, and is sometimes used as such; but in order to save fuel, by displacing water during the first getting up of the steam, it requires to be used the other way up. The same vessel may be made to reverse, and thus answer both purposes, without going into the boiler.

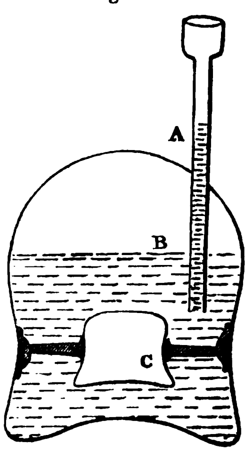
VARIATION IN THE TEMPERATURE OF THE BOILING POINT.

152. Some of the facts concerned in the foregoing experiments are curious, and when first observed apt to lead to paradoxical conclusions, which have been the cause of some confusion in the statements made respecting them by some of our ablest chemists. The subject having a practical as well as a philosophical bearing, inasmuch as it materially affects the proper adjustment of thermometers, and is, on other accounts, which we shall have afterwards to revert to

closely connected with the subject of explosions, we shall endeavour to give such an explanation of what we conceive to be the true theory of it as will be of easy application by workmen and others concerned in constructing boilers. And although this is the first time that the following observations have been published, they are in substance exactly the same as we have frequently given verbally to several scientific gentlemen and eminent engineers in Manchester, Liverpool, London and other places, including Dr. Dalton, Dr. Lardner, Mr. John Farey, Mr. Partington, Mr. Adcock, and many others.

If in a common steam-engine boiler we fix a vessel of any kind inverted, or mouth downwards, as in fig. 12, we shall find that as soon as the water commences to boil, the inverted vessel becomes filled with steam which forces the water out, and the vessel then forms what may be called a steam chamber *below the surface of the water*, but holding steam of greater pressure, and consequently of a higher temperature, than that contained in the ordinary steam chamber *above* the surface of the water, by as many degrees as corresponds to the greater height of the column of water supported by the former.

Fig. 12.



153. Now for all purposes of theoretical comparison, this inverted vessel or submerged steam chamber, or generator, or whatever it may be called, may be considered as the steam chamber of a separate boiler, and the pressure of the steam within it may be calculated from the depth to which it is submerged. For example; suppose the top of the column of water A in the feed-pipe of the boiler (fig. 12) to be three feet above the surface of the water in the boiler, the pressure of the steam which supports it will be fully equal to *one* pound per circular inch, and the temperature of such steam will be, according to circumstances, about 216°; then if we suppose the mouth of the inverted vessel to be submerged to an equal depth below the surface of the water, it is evident that the density of the contained steam must be just double that of the former, or about *two* pounds upon each circular inch, the pressure being in all cases as AC is to AB, and the temperature of such compressed steam will be about 220 degrees of Fahrenheit.

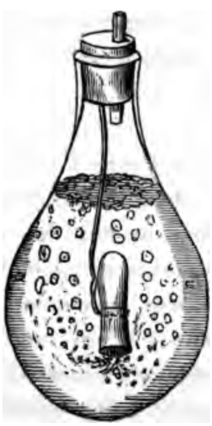
When the boiler is at work, this submerged vessel is continually forcing out bubbles of steam from beneath it, which, by rising up through the water into the ordinary steam chamber, cause a constant agitation or ebullition at all times, and consequently at those times when, but for this circumstance, the water would occasionally not boil at all. In fact, *with the inverted vessel the water boils at a lower temperature than it otherwise would;* but we must here guard against a conclusion too commonly made by parties seeing the experiment tried, that because the water boils at a lower temperature we must necessarily save fuel by the process;—this does not at all follow, any more than that we ought to save fuel in boiling water by means of steam supplied from a separate boiler, which is well known to have no advantage except that of convenience.

154. The fact of the formation of steam under the bottoms of the flues, and under the various projections and bends of

the internal parts of boilers, has been long familiar to boiler makers; and the liability of its occurrence is justly considered by them to be the cause of the greatest difficulties they have to encounter in arranging the parts of boilers of very complicated construction. When this consideration is not attended to in contriving new forms of boilers, such boilers are very liable to become "steam locked", and if those accumulations of steam should occur in any part exposed to the action of the fire, it is probable that such portion of the boiler will become red hot, and consequently liable to produce explosion. We have known several instances of boilers bursting, which have been traced to this cause.

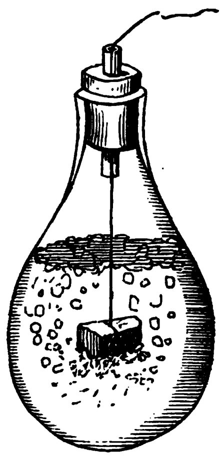
An easy method of exhibiting to the eye the manner in which steam becomes locked or accumulated within an inverted vessel, by an experiment which may be performed on a table, is to boil water in a glass flask over a lamp, and make an inverted vessel of a small glass test tube, tied round with a piece of wire, one end of which is inserted in the cork by which the flask is stopped, taking care to have a small tube inserted through the cork to allow of the emission of the steam as is represented by figure 13 below.

Fig. 13.



A similar experiment may be made with a small piece of broken stone or brick, or any other rough or porous heavy substance, as is shewn by Fig. 14; in this case the substance is suspended by a thread by which it may be alternately drawn above the surface of the water, or immersed below it; thus causing the water to boil or to cease boiling at will.

Fig. 14.



When an apparatus of this kind is seen in action, the steam has the appearance of being *generated* at the under surface of the substance used, from which the latter has received the name of *generator*.

155. According to the Penny Cyclopædia, article "Boiling of Fluids," Dr. Bostock found that the temperature of boiling water varied four or five degrees, according to the presence or absence of extraneous bodies, and at a certain temperature ebullition was suspended or promoted by the same means. For instance, when ebullition first commenced, he found it was very much increased by dropping into the vessel small fragments of cedar-wood; he also found that

the boiling point of ether under similar circumstances varied occasionally to 50 degrees or more.

Previous to the above discovery it was well known that M. Gay Lussac had found two degrees difference in the boiling point, according as the water was boiled in a *tin* vessel or one of *glass;* the latter material requiring the highest temperature; and he concluded that it depended upon the *conducting power* and the *polish* of the vessel in which the experiment was made.

156. Now there is no denying that the conducting power of the material of the vessel must have some effect as to the temperature which that material itself will acquire, but it can have none whatever on the temperature of the water, excepting as relates to the time required to bring the latter to the boiling point; and this depends upon the thickness of the material as well as its conducting power. However, the difference of "*polish*" is quite sufficient to account for the phenomenon in question, if we take the word in a somewhat enlarged sense,—that is, understanding the difference in polish to signify the difference between an extremely smooth surface and a very rough one full of irregular cavities and indentures, and it will then be found that it makes no difference of any consequence whether the vessels be of glass or metal. Many of the minute projections on the internal surface of a boiler allow of small accumulations of steam underneath them, in the same manner as the latter forms under the *generator* in the experiment shewn in figure 14; thus forming small steam chambers, which act precisely on the same principle as the large inverted vessel, already explained (Art. 152, Fig. 12).

157. On observing the above phenomenon in a metallic vessel with a moderately *rough* surface, we might at first suppose from appearances that the steam had a peculiar

tendency to radiate from *points* and asperities; but on a closer inspection of the process it is easily discovered, that those asperities which give off steam in the greatest quantities, have in reality *minute cavities* opening *downwards.* This is at once rendered conspicuous by making a slight scratch or indenture on the inner side surface of any kind of boiler; the bubbles of steam will then be seen issuing abundantly from underneath the little projection or asperity so formed; and this takes place equally of whatever material the vessel may be composed. In the case of glass vessels, the phenomenon is best examined in the common Florence oil flasks, particularly such of them as are frequently found with incidental imperfections and asperities in the glass. If M. Gay Lussac had made his experiments with a cheap apparatus of this kind instead of with probably a smooth and nicely finished glass retort, he would not have been deceived as to the difference between glass and metal, for there can be no doubt that so eminent a philosopher would have immediately detected the cause.

158. In like manner, the experiments of Dr. Bostock may be explained as respects the effects of extraneous substances. The phenomenon he describes is produced by *any substance whatever*, as well as cedar wood, provided that it contains pores or cavities of any kind with their apertures opening downward;—those cavities or small chambers of course allowing the steam to become locked within them, and consequently acting exactly on the same principle as the large inverted vessel or submerged steam chamber before described.

The most striking instance of the effect produced by the immersion of extraneous bodies, is in the case of the thermometer, for if we introduce the naked bulb only of the thermometer into the heated fluid when the latter is at a temperature a little below the boiling point, no effect whatever is produced, but if along with the thermometer the lower part of the attached scale (whether of wood or metal) is introduced, bubbles of steam are given off immediately although the temperature remains constantly the same.

159. Similar effects to those above described must have been frequently produced during some part or other of the manipulations of almost every experimenter since the time that thermometers were first invented; yet familiar as they must necessarily have been to every chemist, it does not appear that any one has hitherto published any satisfactory explanation of them, although statements descriptive of the phenomena, and to the effect that they were first observed by M. Gay Lussac, have been published in almost every chemical work for a great number of years past.

It is stated in Professor Graham's very excellent work recently published*, that "the reason why water in these circumstances does not pass into vapour at its usual boiling point, *is not distinctly understood*," and he afterwards adds in illustration, that "the water appears to be in a precarious state of equilibrium." Now may we not here inquire *why* it has not been understood, and suggest the probability that it is because it was *too easy* to understand; or in words, the proper explanation was too plain and simple, and in consequence overlooked. If the explanation had involved the sciences of Electricity, Galvanism or Magnetism, or all three together, it is extremely probable that it would have been found out long ago; for many of our chemists, like certain politicians, are usually looking so far abroad that they seldom see objects which lie directly in their way until they stumble over them.

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* Elements of Chemistry, including the application of the Science to the Arts. By Thomas Graham, F.R.S.L. & E. Professor of Chemistry in the London University College, &c., &c.

160. We have now, it is hoped, given a sufficiently comprehensive account to enable any one to perceive, at a glance, the rationale of water and other fluids being more easily converted into steam when in contact with rough and uneven surfaces than when the surfaces are smooth and polished, as well as a reason for the apparent fact consequent upon it, that it requires a higher temperature to boil water in vessels of glass than in those of metal. But there are also variations in the temperature of the boiling point produced by other causes than those pointed out. Professor Graham states, on the authority of Mr. Scrymgeour of Glasgow, "that if oil be present with water, the boiling point of the water is raised a few degrees in any kind of vessel," which is a fact of some consequence, perhaps, to those who recommend the putting of oil or tallow into boilers. Another cause of variation owing to the ever varying barometrical pressure of the atmosphere, is too obvious and almost too well known to need adverting to, except for the purpose of introducing the following table of temperatures corresponding to each quarter of an inch of the usual range of the height of the barometer, which will be found useful to refer to by those who may be inclined to follow up the experiments mentioned in this section.

When the barometer stands at	Distilled water boils at
28 inches	208½ degrees.
28¼	209
28½	209⅓
28¾	209⅔
29	210
29¼	210½
29½	211
29¾	211½
30	212

When the barometer stands at	Distilled water boils at
$30\frac{1}{4}$ inches	$212\frac{1}{2}$ degrees.
$30\frac{1}{2}$	213
$30\frac{3}{4}$	$213\frac{1}{3}$
31	$213\frac{2}{3}$
$31\frac{1}{4}$	214

EXAMPLE OF LARGE BOILER CONCLUDED.

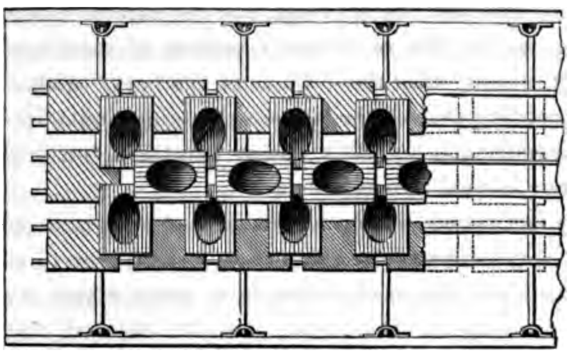
161. Resuming again the consideration of the large boiler, (from Art. 119,) it will be found that instead of lowering the water surface, or putting a flue through the boiler, in order to lessen the quantity of water, it will be much more advantageous and out of all comparison cheaper than the latter, to place in the boiler a number of sediment collectors or generators, so as to occupy a considerable portion of the water space, as shewn in figs. 10 and 11. The terms *collectors* and *generators* are used indifferently, because the same articles answer both purposes accordingly as they are placed with their concave faces upwards or downwards, and in either way they are equally eligible for the purpose of replacing the surplus water and thereby saving fuel.

To assure ourselves, however, of effecting the latter purpose in all cases, namely, the great desideratum of saving fuel, a certain arrangement of the collectors is absolutely necessary in order to consult the convenience of the men employed about them. For although it is impossible, perhaps, to place them wrong, or so that some saving will not occur, unless it is done intentionally, yet it is much better to avoid the possibility of failure in the introduction of all new improvements, and more especially in all such as are circumstanced as the one we are speaking of, where the operation is of a disagreeable kind at the best, and all but inaccessible to a master or manager's superintendence. That such an arrangement can easily be made in this instance will be immediately shewn; and it may at the same time be also stated, for the benefit of that proverbially unfortunate class of inventors, usually (in Lancashire) called "schemers," that there is an infallible rule applicable to all sorts of new inventions or improvements, which if followed will insure the good management and eventual success of the latter, providing that they are *real* improvements,—but the willing cooperation of the employer, or those principally to be benefited by the improvement, is indispensable. The rule is:—Make the new process such, that while the work of those employed about it requires less labour and trouble than it did before, they have more for doing it; or, in other words, make it a mutual benefit to both masters and men, and it is sure to answer. This is a well known truism with both employers and employed in all manufacturing establishments, but it appears far from being so amongst those who come under the general appellation of schemers,—hence their everlasting complaints and charges of ignorance and prejudice against workmen. It is all very well for inventors to say that masters ought to *compel* their men to do so and so,—factory masters at least know well enough that it is not so easy. Ingenious mechanics, who are able to make iron and wood do almost any thing, are too apt to forget that flesh and blood are materials of a far more intractable kind; but they may rest assured, on the word of one who has had many years' experience in all the three capacities above mentioned, that nothing but attention to the above advice will either command or deserve success.

162. The best directions respecting the collectors are as follow:—In the first place, they require to be made sufficiently heavy not only to prevent the possibility of their floating when the water is first put into the boiler, but also to prevent their moving or getting in any way displaced by any agitation in the water; this is accomplished by making them of fire clay, and well burnt, about 18 or 20 inches long,

12 broad, and 4 to 6 inches thick, with an oval shaped concavity on one side of sufficient capacity to take away about one half of the material; with these dimensions 36 of them occupy about a cubic yard, and cost about eighteen pence each. They must be placed upon inch square bars of iron laid over the stays, as is shewn in section in figs. 10 and 11, page 126, and in plan in fig. 15. One or two of the bottom tiers being placed with their hollow sides downward to act as generators or steam collectors, and also to serve as a foundation for those placed the other way up, or as sediment collectors. The latter answer best for catching the dirt when placed quite as high up as to be level with the surface of the water, and those that are below require to be partially covered by other collectors, but so as to allow sufficient room for lading out the dirt into a bucket without removing the latter.

Fig. 15.



CHAPTER IV.

GENERAL PRINCIPLES OF CONSTRUCTION IN FORM AND PROPORTIONS, TO COMBINE EFFICIENCY, ECONOMY AND STRENGTH; WITH RULES AND TABLES FOR SETTING OUT THE DIMENSIONS OF NEW BOILERS.

163. ONE of the most prevalent sources of error to practical men, is the apparent paradoxical fact, that whatever length a boiler may be made, the heated air which escapes is still capable of boiling water in a separate vessel placed in the flue leading to the chimney, which naturally induces a suspicion that our ordinary methods of combustion only produce a small portion of the heat derivable from the fuel. Hence the thousand and one schemes, and the various winding and zigzag flues, of the numerous inventors of boilers, who are mostly running after the "*whole* of the heat," with a fatuity far exceeding that of the perpetual motion hunters—the latter generally give up after one or two trials, but the former continue as mad as ever.

The fact stated, however, is in no way surprising, although steam may be thus raised in a close vessel, even to a greater pressure than that in the boiler from under which the waste heat has escaped. It certainly must be allowed, that steam so obtained, if returned into the boiler at a workable pressure, is *so much* clear gain—our argument, however, only is, that it is *not much;* in fact, if we calculate it commercially, it is worth less than nothing, that is, if we take *time* into account, or according to what we have elsewhere observed, we find it to be produced at so slow a rate that its value is less than a very small per centage on the capital employed to obtain it.

In taking this view of the subject, it must always be remembered, that the limits we have laid down (in Chap. I.) as including an average of the best practice in Lancashire, will admit of considerable variations in different times and places, according to the price of materials and the value of money.

164. As a general principle in the construction of boilers, it must be admitted that we ought to select that form which gives the proper quantity of heating surface, along with the greatest capacity, as well as strength, for the quantity of materials employed. The two last conditions would lead us to prefer the spherical form; and if it were absolutely necessary to have the furnace within the boiler, a form approaching to this might still be the best, as in the fire-boxes of some of the best locomotive engines. The old fashioned, or "haystack" boiler, is also a near approach to this shape, and up to a certain size it is yet perhaps as good as any, when well made; but the concave bottom requires to be supported by stays, which add to the complexity of the construction.

165. The next in degree, for simplicity of form, is the horizontal cylinder, and it is almost a necessary requisite, to insure the greatest strength and perfection of workmanship, that it be made without any inside flue. This form admits of a fire-grate of the full width of the boiler, and the products of combustion may be advantageously applied to nearly the whole of the lower half of the external surface. Accordingly, we have always found a prevailing disposition amongst manufacturers to adopt the cylindrical form, either with or without inside flues, although the practice has not hitherto been so generally successful as that of Boulton and Watt. There seems to be an admitted difficulty in adapting the fire so as to act uniformly against the convex boiler bottom; but their greatest faults have arisen from imperfect methods of setting,

being frequently set up like wagon boilers, with winding flues, to which their form is not at all adapted.

THE CYLINDER OF GREATEST CAPACITY.

166. In order to give a general investigation of the best proportions for the cylindrical boiler, according to the same principles which we have applied to others, we shall first ascertain what are the proportions of a cylindrical boiler, when it has the greatest capacity for the least weight of material.

This investigation is generally considered to require a fluxionary process, and many able workmen have been on that account deterred from examining for themselves the well known proposition, that a cylinder, whose length and diameter are equal, has the largest capacity for a given surface; and they are thereby prevented from placing any faith in the various useful rules which are deduced from it. An easy method of proving the truth of this proposition is therefore introduced, with a view to its being useful to operative mechanics, who will perhaps not the less appreciate it when informed that it was the production of one of their own "order," before the schoolmaster was "abroad," and consequently, also, without the multifarious aids of Mechanics' Institutions, or of the various lucid treatises of the Diffusion Society.

Proposition. — To find the length and diameter of a cylindrical boiler, of a given weight of metal, when its cubic contents are a maximum; or, which is the same thing, to find the proportions of a cylinder, of a given capacity, when its superficial area of surface is the least possible:—

Solution by the Soho, or Routledge's slide rule.—Invert the slide, and set 1 on C to the given capacity expressed in *cylindrical units* on A, say 64, as in the following example. Then the logarithmic line A, will represent a series of numbers, which are the areas, in *circular units*, of the ends of all possible cylinders of the given capacity. The numbers on the line D, being the square roots of those areas, will represent the diameters of the various cylinders; and the corresponding numbers on the inverted lines B and C will represent the lengths of those cylinders respectively.

EXAMPLE.

A	15	16	21⅓	32	64	Areas.
C	4·27	4	3	2	1	Lengths.
B	4·27	4	3	2	1	Lengths.
D	3·87	4	4·618	5·65	8	Diameters.
	16·52	16	13·85	11·3	8	Products.
× by 4 =	66·08	64	55·4	45·2	32	Convex Surfaces.
	30	32	42·6	64	128	End Surfaces.
Sums	96·08	96	98·0	109·2	160	Total Surfaces.

Now while the areas of the ends of the cylinders *decrease* as the squares of the diameters, the areas of the convex surfaces must *increase* as the length of the cylinder multiplied by its circumference, (but divided by ·7854 to reduce the *square* measure to *circular*, in order that the end surface and the convex surface may be expressed in units of the same denomination,) and as the circumference is 3·1416 times the diameter, the area of the convex surface will always be (3·1416÷·7854=) four times the diameter multiplied by the corresponding length. Therefore, in order to obtain a series of numbers representing the areas of the convex surfaces of the various cylinders, we have only to multiply their respective diameters by their corresponding lengths, and these products again by 4, beginning at the right hand as in the above example. At the same time we must add twice the *end* area of the respective cylinders to the *convex* area as thus found, and the sum will be the total area of surface of each. By proceeding with this operation (which may generally be done mentally) towards the left hand, we shall soon find, that that sum is the least possible where the length and diameter are equal, or in the above example 4 and 4, and consequently equal to the cube root of the capacity.

In like manner if we take a cylinder of any other capacity we shall always find that the length and the diameter are each equal to the cube root of the capacity in cylindrical measure, when the superficial area of surface is the least possible for the given content.

167. This application of instrumental arithmetic will perhaps be better understood by the general reader, after considering the analogous method of resolving the simpler problem in article 117. And although some of the lovers of the "higher analysis" will no doubt consider this as one of the few problems which Emerson long since rather contemptuously admitted might be "*hammer'd out with great labour and difficulty by other methods*" than by that of fluxions*, yet it will not perhaps be less approved of

* The following is Emerson's own solution of this problem, from which the reader, whether initiated or not, will be able to judge of the comparative logical clearness of the two methods, — infinitely superior as Emerson's is, to those we usually see with the modern refinements of the differential calculus.

To find a cylinder of a given solidity (b), with the least whole surface.

Let y=altitude, x=diameter of the base, c=3·1416,

Then, $\frac{cx^2y}{4}=b$.

And $\frac{cx^2}{2}$=sum of the bases,

cxy=convex surface$=\frac{4b}{x}$;

Therefore $\frac{cx^2}{2}+\frac{4b}{x}=m$ (*a minimum*):

on that account, as it forms the foundation of some useful applications of the slide rule for the every day practice of the mechanic, and which we shall here introduce.

168. Suppose we require the dimensions of a cylinder capable of containing two imperial gallons, say 554½ cubic inches when the quantity of material of which it is made is a *minimum*. Here we must divide the cubic capacity by ·7854 which gives 706 cylindrical inches. The slide rule will then stand as follows:—

SOHO RULE, SLIDE INVERTED.

A	79·2	81		100	353	706	Areas.
Ɔ	8·9	8·71		7·06	2	1	Lengths.
ꓭ	8·9	8·71		7·06	2	1	Lengths.
D	8·9	9		10	18·7	26·5	Diameters.

Here we find the required diameter and length each equal to 8·9 inches, which is the cube root of the capacity *nearly*, and will be found on trial, as before, to be nearer the truth than either of the numbers on each side, how near soever they may be taken.

169. Corollary:—Hence as the cubic contents of the above cylinder is a maximum, half of it, taken along with its corresponding half of surface, is also a maximum; consequently, if we suppose it to be cut by a plane perpendicular to the

---

In Fluxions $cx\dot{x}-\frac{4b\dot{x}}{xx}=0$,

Which reduced gives $x=\sqrt[3]{\frac{4b}{c}}$,

And thence $y=\sqrt[3]{\frac{4b}{c}}=x$.

axis of the cylinder, we shall have two cylindrical vessels or measures of 8·9 or $8\frac{7}{8}$ inches diameter and $8{\cdot}9 \div 2 = 4{\cdot}45$ or nearly $4\frac{1}{2}$ inches deep, each capable of holding an imperial gallon with the least possible quantity of surface, or material of a given thickness.

170. From the above we deduce a very useful formula for enabling boiler-makers, ironfounders, or coppersmiths, to proportion any kind of open cylindrical vessel, so that it may contain a given quantity of cubic contents with the least possible quantity of material of which it is made, as follows:

FORMULA FOR SOHO RULE, SLIDE INVERTED.

A	No. of cylindrical inches, feet, yards, &c.
Ↄ	Gauge point = 2.
ꓭ	Diam. of vessel in inches, feet, yards, &c.
D	Ditto; half of which is the depth.

Set 2 on C to the given capacity in cylindrical measure upon A, and then the two numbers which coincide on the lines B and D, or the cube root of double the capacity, is the diameter of the vessel required, and one half of which is the depth.

171. To save the trouble of reducing cubic to cylindrical measure, it is only necessary to use another gauge point instead of 2, which is obtained in the following manner:—

Say by proportion, as cylindrical measure, is to cubic measure; so is the old gauge point to the new. Or, As ·7854 : 1 :: 2 : 2·546, hence the new gauge point is a little more than $2\frac{1}{2}$ or nearly $2{\cdot}5\frac{1}{2}$, which latter number is used in the following examples.

Example 1. Required the dimensions of a cylindrical *gas-holder*, to hold 20,000 cubic feet of gas, (independent of the rise of the dome top,) to be made with the least possible quantity of superficial area of surface.

SOLUTION BY THE SOHO RULE, SLIDE INVERTED.

A	Given contents in cubic feet=20,000.
Ɔ	The gauge point= 2·5½.
ꓭ	37 feet=Diameter required.
D	37 feet, half of which is the depth=18 feet 6 inches.

Example 2. Required the dimensions of a cast iron *kier*, to contain 2,000 gallons, with a given thickness of metal, and to be the least possible weight. Here we must first reduce the gallons to cubic feet, there being nearly 6¼ gallons, or exactly 6·232 in each cubic foot, which gives 320 cubic feet; then the operation is as follows:—

SOHO RULE, SLIDE INVERTED.

A	320 cubic feet, the given content.
Ɔ	2·5½ the gauge point.
ꓭ	Diam. required=9·3½ feet.
D	Ditto =9·3½, half which is the depth=4·67 ft.

172. It is hoped that the above rules and examples for the slide rule will be useful to practical men generally, as well as to working mechanics, many of whom very properly deprecate the use of any more algebra than is absolutely necessary.

There are a great many physical problems that are quite capable of being investigated in a similar manner to the above, where the calculation and demonstration are carried on and made sufficiently clear in the same operation. Not unfrequently indeed, the very best way of carrying on such investigations is by arithmetical means alone. A memorable instance of the latter may be cited as being not quite so well known even to engineers as it deserves. We allude to the assertion of Tredgold (based upon a fluxionary investigation) that in a rotatory engine *nearly one half of the power of the steam is lost!* which assertion was most effectually disproved in two or three lines of common arithmetic by a correspondent of the Repertory of Patent Inventions for September 1828, although the algebraical theory was vainly endeavoured to be supported by other writers, including Mr. Tredgold himself, in the succeeding numbers of that journal.

The discussion was short but curious, as exhibiting in some of the parties to it, a strange tenacity of opinion, combined with a perverseness that is seldom witnessed except in political or religious controversy. For although the arithmetical proof was quite as conclusive as that two and two are four, (which by the by was almost literally the point in dispute,) yet the editor of the Repertory again reiterated the fallacious principle in question, on the occasion of reviewing a patent for a rotatory engine in the same journal two or three months after, and gave Tredgold as a satisfactory authority for the assumed loss of power, thus causing, very probably, a *real loss* to the patentee by depreciating his invention in the eyes of the public.

173. Absurd as is the upholding of error in a work which for some reason or other a reviewer may have made up his mind to praise, it is something worse when a condemnatory course is pursued; more particularly when dogmatic opinions are given in relation to subjects of so practical a nature as is yet that of the steam engine and boiler,

with which most extensive interests are so intimately concerned, not only as to the immense capital involved in patents, but as relates to the immense number of obscure but laborious and deserving individuals who never have the means of procuring patents, but are nevertheless daily adding to the improvement of steam machinery.

It is not difficult to perceive that there has been recently, a greatly increased tendency to dictation on the part of sundry M.A.'s and M.Inst.C.E.'s, which is highly reprehensible, and, if unchecked, likely to effect, merely through the weight of great names, incalculable injury on all persons concerned in improving machinery. The lesson which the Great Western steamer read Dr. Lardner, seems yet to be quite lost upon others of the same school. The discussion above mentioned is a most instructive, although humiliating lesson, to those who are ever ready to subscribe to the positive dicta of mathematicians, and we therefore strongly recommend it to the notice of all those who have busied themselves in exposing what they call the "fallacies" of the Rotary engine scheme, more especially as Tredgold's theory has been recently revived in the new edition; being renovated in all the delusive garb of the differential calculus, which the editor has substituted for the fluxions of Tredgold. In justice to the publisher, however, it must be stated, that the mistake is properly corrected in the list of errata, at the end of the work.

174. In order to point out more palpably to the working mechanic, the inexpediency of generally wasting his time and resources in acquiring a necessarily imperfect knowledge of abstract mathematics, perhaps we cannot do better than insert Dr. Ritchie's method of resolving the problem of the maximum cylinder; and which is for that purpose here copied from his work on the principles of the calculus, by which also the before mentioned methods of arriving at the same result will be more apparent.

"Let c denote the capacity of the cylinder in cubic inches, x the radius of the base, and y the height of the cylinder, and $\pi = 3{\cdot}1416$.

Then $\pi x^2 =$ area of the base, $2\pi x y =$ area of the convex surface, and $\pi x^2 y = c$.

Hence, dividing both sides of this eq. by x we get

$$\pi x y = \frac{c}{x} \text{ or } 2\pi x y = \frac{2c}{x},$$

another expression for the convex surface.

Hence, $\pi x^2 + \frac{2c}{x} =$ whole surface which is a minimum.

Differentiating we have $2\pi x dx - \frac{2cpx}{x^2} = 0$.

Hence, $2\pi x dx = \frac{2c dx}{x^2}$ and $2\pi x^3 = 2c$.

Consequently, $x = \sqrt[3]{\frac{c}{\pi}}$.

Again, since $\pi x^2 y = c$ we have $y = \frac{c}{\pi x^2}$.

Therefore, $y = c \div \frac{\pi c^{\frac{2}{3}}}{\pi^{\frac{2}{3}}} = \frac{c^{\frac{3}{3}}}{\frac{\pi c^{\frac{2}{3}}}{\pi^{\frac{2}{3}}}} = \frac{c^{\frac{1}{3}}}{\pi^{\frac{1}{3}}} = \sqrt[3]{\frac{c}{\pi}}$.

Consequently, by substituting the value of x we have

$$y = \frac{c}{\pi \frac{c^{\frac{2}{3}}}{\pi^{\frac{2}{3}}}} = \frac{c^{\frac{3}{3}}}{\pi \frac{c^{\frac{3}{3}}}{\pi^{\frac{2}{3}}}} = \frac{c^{\frac{1}{3}}}{\pi^{\frac{1}{3}}} = \sqrt[3]{\frac{c}{\pi}};$$

which being the same expression as that obtained for x, it follows the height of the cylinder must be equal to the radius of the base."

The above specimen of the learning inculcated at the London University, is a fine example of the best possible method of puzzling a very plain matter. No wonder that among those, whose resources allow them to repair to the universities, as is remarked by Professor Airy, "The results of the differential calculus are received by many, rather with the doubts of imperfect faith, than with the confidence of rational conviction."*

ON THE LENGTH OF BOILERS.

175. When a boiler is to be set up in the simplest possible manner, that is, without flues of any kind, it is of some consequence to know to what length the flame is likely to extend; because on this will depend, in some measure, the extreme limit of the boiler as to length. We have before shewn, that a square yard of heating surface to each square foot of fire grate, with a proportional space for the flame to develope itself in, is amply sufficient to produce, with the greatest economy, a sufficient supply of steam at the *rate* and *pressure* required by a well made Boulton and Watt engine—that being, in fact, an average of the best practice. But there is another question to be examined, which is, whether it is better to obtain the necessary heating surface in as compact a space as possible, in the immediate vicinity of the furnace, or by means of comparatively long narrow flues, either winding or otherwise.

In accordance with reasons before given, (Art. 31,) we have always preferred having as much of the boiler bottom as possible exposed in the furnace to the direct action of the fire and flame; and experience has since determined the propriety of this practice.

In using fuel with little or no flame, it is evident that a boiler of a form approaching as nearly as convenient to that

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* Principles of the Differential and Integral Calculus, by the Rev. William Ritchie, LL.D., F.R.S., Professor of Natural Philosophy at the Royal Institution of Great Britain; and Professor of Natural Philosophy and Astronomy in the University of London. 1836.

of the equal cylinder, or cylinder of greatest capacity, would, as proved by the foregoing investigation, be the best for *economy* in first cost, and, if made with hemispherical ends, would also be the best for *strength*. Therefore a boiler of this form, whose length is equal to twice its diameter, will be the shortest that can be conveniently adopted in any case. And there is no doubt that, if expedient, such a one might be beneficially adopted where coke or anthracite coal is the fuel used.

176. There is a current opinion amongst experienced workmen, that the common wagon boiler ought to be about three or four times the length of the fire-grate, to insure a good effect; and it is based upon the observation, that when a boiler is set up with that proportion, the whole of the flame is expended against the under surface, and never passes into the side flues along with the smoke. The truth of this observation, however, depends upon circumstances. With boilers whose fire-grates are square, and whose lengths are not less than four times that of the fire-grate, we have never met with an instance of the flame reaching to the end of the boiler, provided that there was a *good draught* and the fire *properly managed*. These conditions are important, as will be easily perceived; for if the draught is bad, and the fire allowed to burn sluggishly, or with an imperfectly developed and dull or reddish flame, the effect is then like that of an unsnuffed candle, or badly managed gas light; the flame is of greater length but of less intensity, and is consequently capable of carrying a very low degree of heat to a greater distance. Even where the chimney has a good draught, should the furnace not be kept regularly cleaned, and the fire-bars free from clinkers, or if there should be a great mass of coal thrown upon the fire at once, the consequence is nearly the same. In such a case the fire becomes, in fact, little better than a gas retort; and the gas so made

has been frequently known to fill the chimney, so as to take fire at the chimney top and burn like a gas light, while at the same time, for want of the proper supply of oxygen, there was little or no flame at all under the boiler.

177. Whether there is any thing to be gained in making a boiler of a greater length than four times the length of the fire-grate, other conditions being equal, there have been very few direct experiments upon a large scale to determine. The only experiment, of which the result has been published, bearing in some degree upon this question, is one by Mr. Stephenson, of which some account is given at page 524 in Mr. Nicholas Wood's work on railroads *. The experiment was made with the boiler of a locomotive engine similar to that of the "Rocket," when the fact of the very much greater evaporating power *(per square foot of surface)* of the fire box than that of the rest of the boiler containing the tubes, was decidedly proved, and the difference found to be so very considerable, that it had properly great influence in producing the present practice of making locomotives with very large fire boxes; a practice which has proved to be eminently successful.

178. M. Pambour regrets that such experiments had not been more frequently made, and without which, he appears to think it a difficult matter to settle the true *theory* of the locomotive steam-engine. However, if English mechanics only succeed in the *practice*, they will, no doubt, willingly leave to the French mathematicians all the glory of discovering the exact theory some twenty years hence. There can

* A Practical Treatise on Railroads and Interior Communication in general. By Nicholas Wood, Colliery Viewer, &c. Third edition, London, 1838.

be no doubt that experiments have been made on this subject by various engineers and manufacturers for their own guidance in practice, but who have had no sufficient motive for publishing them. We never made but one experiment on this particular subject, which was as follows:—an open topped boiler was made and divided by water-tight partitions into four equal divisions, each nearly filled with water; a coal fire was made upon a square fire-grate, under one end, of exactly *one sixth* the length of the boiler; the fire was treated in the usual manner, and each division of the boiler was supplied with water in all respects similarly to an ordinary steam-engine boiler, except that this was open to the atmosphere. It was then found that the difference between the quantities of water evaporated in the first and second divisions, was something like that in Mr. Stephenson's experiment, but the quantity of water evaporated from the third division was amazingly diminished, and in the fourth division the evaporation was practically nothing, or so small as hardly to bear any comparison to the whole. As this experiment was not conducted with strict scientific accuracy, it is unnecessary to publish our notes of it, but it may be as well to state, that it had all the advantage (if it be any) of a bad draught; being made with a temporary furnace built for the purpose in an open shed, and with merely an outlet for the smoke to pass into a common house chimney.

179. The general result of the above experiment was sufficient to determine what has since been our uniform practice in recommending that the length of boilers should not in any case exceed *six* times their width, supposing the latter to determine the size of the square fire-grate. This advice has been extensively acted upon for some years with uniform success, there being some instances of boilers with a proportion of only five to one, and they are found to be

nearly as economical as any other kind when equally well made and properly managed; of course we are speaking of boilers *without return* flues or internal flues of any kind.

180. If a cylindrical boiler be set up with winding flues or a wheel draught, of course its length may be advantageously reduced in the same proportion as in wagon boilers that are set up in the same manner, or to about *four* times their width. But this is a method of setting cylindrical boilers which is decidedly objectionable, on account of its causing the seating walls to encroach too much upon the necessary width of the furnace; or if the latter is made sufficiently wide, then the side flues will be found too small, unless gathered in above the centre line of the boiler, and thus rendering the upper part of the side surface almost useless as heating surface, except when the flues are carried above the level of the water, and then it is pregnant with danger.

181. When a cylindrical boiler has an inside flue, and is set up with a split draught, as described in article 12, the above objections do not so fully apply, because the smoke is then divided into two currents, and the side flues only require to be half the size of the former. If a boiler of this kind with the uptake *inside* the boiler, similar to that in fig. 5, so that a portion of the flame may occasionally pass into the inside flue, the length of the boiler will then admit of being reduced to about *three* times its width; and this in fact is the exact proportion used in factory boilers, in many instances, and is found to be exceedingly economical.

182. Wagon-shaped boilers are certainly amongst the most economical boilers in regard to fuel to be met with in the cotton factories, and by far the greatest number of them are

somewhat shorter than the proportion stated above, and may fairly be considered as affording the safest guide in practice.

From the consideration, that the above remarks, together with the observations heretofore mentioned, point out the proper limits in practice for all kinds of boilers as respects length, we have drawn up the following empyrical rules, which are nearly equally applicable to all the simpler sorts of boilers that are used in factories, whether wagon shaped or cylindrical.

183. *General Rules for proportioning the length of boilers.*

Rule I. A plain boiler without any inside flue, to be hung upon what is called the "oven plan,"* ought not to exceed in length *six* times the square root of the horse power in feet, or in ordinary circumstances, *six times the square root of the area of the fire-grate in feet.*

Rule II. A boiler without any inside flue, to be set up in the common way with a *wheel draught*, ought not to exceed in length *four* times the square root of the horse power; or *four times the square root of the area of the fire-grate in feet.*

Rule III. If a *flued* boiler, or boiler containing one or more inside flues, (and the latter pass *quite through*,) is to be set up with a split draught, it ought not to exceed in length *three and a half times the square root of the horse power*, and if with a wheel draught, three and a quarter times the same, or *three and a quarter times the square root of the area of the fire-grate in feet.*

Rule IV. If a *flued* boiler with an *inside uptake*, like a Boulton and Watt boiler, (Art. 82,) is to be set up with a

* That is, without any return flue, but with the flame and smoke to pass from the fire place directly under the bottom of the boiler to the vent or chimney. When the draught is arranged in this manner, it is by some called "a *thorough* draught."

split draught, it need not exceed in length from *three to three and a quarter times the square root of the horse power;* or if it is to be set up with a wheel draught, then the length of the boiler ought not to exceed *three times the square root of the horse power, or of the area of the fire-grate in feet.*

184. Boilers whose proportions are represented by the above practical rules, are mostly the best to be found of each kind in Manchester, more especially those indicated by the three last. But the manner of hanging boilers to which the first rule relates, is yet more generally confined to other places, where inferior workmanship only can be obtained, and where the space occupied by the greater length of the boiler is not generally of so much value; it has also been almost exclusively confined to cylindrical boilers; consequently the data for this rule have not perhaps been quite so exactly determined as for the others.

There are reasons for supposing that cylindrical boilers might be considerably shorter than the proportion stated in Rule I., if the fire could be equally well arranged as in the wagon boiler; but there is a difficulty in applying the fire to the bottom of a boiler of this kind as compared to a wagon boiler, the concave bottom of the latter being admirably adapted to this purpose, because the centre of the grate where the heat must be the most intense, is at the greatest distance below the boiler bottom, while the latter gradually approaches nearer to the grate at the sides of the furnace, and thus tends to equalize the action of the fire. Now the bottom of the cylindrical boiler being *convex* downwards, of course the action of the fire against it is exactly the reverse of the former. On this account there requires to be a greater average distance between the fire-grate and the boiler bottom; this again requires a greater quantity of coal in the furnace at one time, which both impedes the draught and causes the flame to be occasionally extended in length in the manner already described, (Art. 177.) Hence the boiler requires to be proportionally extended in length also.

ON WASTE HEAT.

185. From the above considerations it appears that but for the difficulty of having the fire equally well managed, that a ratio of *five* to one, instead of *six* to one, is an equally eligible proportion for the length of a cylindrical boiler with a *thorough draugt*, as that of *four* to one is, when applied to a common wagon boiler with a *wheel draught*. But until the plain cylindrical boiler has come more extensively into use, so as to afford more numerous experiments and observations, we shall only err on what is usually considered the saving side, by adopting for the present the greater ratio of six to one.

The general leaning of many manufacturers to erroneous opinions respecting the proper length of boiler, as well as the proper quantity of heating surface, namely, that they may both be almost indefinitely extended with advantage, renders it necessary to observe, that we have had very many opportunities of comparing the effect produced by lengthening boilers, but never yet met with one iota of saving accruing from such alterations, excepting where there had been previously a deficient quantity of heating surface or of steam room.

186. The exceptions just stated are important, and require to be especially noticed; for the neglect of them is, in fact, generally the cause of much self-deception on this and kindred subjects. A manufacturer, for instance, has got his engine overloaded, without his knowing it, except from the increased consumption of coal, arising from the necessity of overfiring a boiler too small for the work it has to do. He then finds, perhaps for the first time, that the temperature of the smoke in the chimney flue is four or five hundred de-

grees; and knowing that the heat of the steam is little more than 212°, he hastily concludes that about one half of the heat produced by the fuel is sent up the chimney and lost; and he consequently gives a ready assent to the use of any plausible means of "*robbing* the smoke of this waste heat" before it escapes. Hence a boundless field of speculative enquiry is opened, and how to *use up* the *whole* of the heat in the most advantageous manner, becomes a question of intense interest to those whose establishments require an expenditure of a few thousands a year for fuel.

Consequent on observations of the above nature, we have patent inventions without number for returning the "caloric" of the smoke, by passing the latter through variously contrived systems of tubes and channels which separate it from counter currents of fresh atmospheric air; this air being thus "charged with caloric" on its passage, is then used to supply the combustion in the furnace.

Owing to the great success attending Mr. Neilson's hot air system in iron works, there is a certain degree of plausibility in applying similar plans to the above to steam-engine furnaces; and when sufficiently involved with the ordinary vague and half obscure notions of smoke burning, they form the foundations of nearly one half of the smoke burning patents with which we are acquainted.

187. The principle of returning the heat of the smoke has been well tried in various ways in Manchester; and of the details of which trials we have in many cases preserved notes; but which, as being proofs of abortive schemes, we would be sorry to inflict on the readers of this work; and it is rendered the less necessary, as the forthcoming volume of the "Manchester Philosophical Society's Memoirs" is expected to contain papers relating to this subject by a gentleman well qualified to do it justice. The general result, however, is instructive, and may be shortly stated to be as follows:—the

saving in fuel at a steam-engine furnace, by heating the air that supplies the combustion, is exactly equal to that which is lost, or rather not created, in consequence of the diminished draught; consequently this system of saving fuel is exactly that of "robbing Peter to pay Paul," and the effect is uniformly the same whether the air is heated by the same furnace or a separate fire.

The plan most commonly resorted to, however, for reducing the temperature of the chimney, is to lengthen the boiler; and notwithstanding the diminished draught, the result in all such cases as we have supposed above, (Art. 186,) is, that the manufacturer finds a certain saving in fuel, and he usually ascribes the improvement solely to the lengthening of the boiler and consequent extension of the distance that the smoke and hot air have to travel before they escape, forgetting that the increased quantity of heating surface and boiler room may be quite sufficient to produce the increased economy in fuel, as, in fact, is the case 99 times out of 100.

188. Correctly recorded experiments in all cases support the position we wish to enforce; which is, that in a well proportioned boiler *there ought always to be a sufficient area of heating surface within as short a space as possible.*

The propriety of a practice founded upon this principle was conclusively settled at that great era of steam engineering, the opening of the Liverpool and Manchester Railway, by the success of Messrs. Stephenson and Booth's locomotive "the Rocket;" and the more closely this principle has been adhered to since, the more perfect has been the railway locomotive boiler for *efficiency and economy combined.* And as it is always good to recur to first principles, railway engineers would do well to bear the above facts in mind; for the principle they involve points to the necessity of increasing the number of tubes, and consequently the diameter of the boiler, rather than the length; and which is an argument in favour of the wide gauge, that seems to have been overlooked in the late investigations respecting the Great Western Railway.

189. In adverting to the improvements effected or attempted, about the time of the opening of the Liverpool Railway, we cannot help mentioning some evaporation experiments which were then made with some patent boilers, constructed upon a principle completely opposite to that recommended above; that is, consisting of long, winding, continuous flues. In those boilers it was alleged that the heat was all so *entirely used up* by their extraordinary economical qualities, that the caloric evolved from the fuel was so completely abstracted by the rapid generation of steam, and the heated air and incombustible gases so far robbed of their heat and cooled down, that *the hand or arm might be placed with impunity inside the tube* from which the smoke escaped from the boiler. We forget whether this experimental way of proving too much was an Irish invention or not; at any rate it was an improvement upon the "robbing Peter to pay Paul" system. If we recollect right, it was gravely alleged to save *one hundred and twenty* per cent. in fuel; and a report to that effect was published in some of the journals of that time, to which the names of some eminent engineers were attached.

190. In some attempts to save waste heat, separate boilers have been added, and completely inclosed in large flues leading from the boiler to the chimney, without the least perceptible result as to saving of fuel. These additional boilers, or heat savers, or "thrutchers," (as they have been technically termed in Lancashire, on account of their supposed assistance to a larger boiler,) are sometimes made without any steam room, and applied solely to the purpose of heating, or rather only of *warming*, the water for feeding the larger boiler. It is also true, that by such means the

water has been considerably elevated in temperature, previous to passing into the boiler; yet *exactly* how much heat has ever been saved by them, we believe is yet a question for the philosophers; but if we may judge of the quantity of heat saved by its effect in saving fuel, it differed from nothing (if not quite nothing) by less than any assignable quantity.

In one case to which our attention was particularly directed, it was found that the *heat savers* succeeded in making the water within them nearly as hot as that in the boiler; yet it was observed that there was only a difference of a very few degrees of temperature in the water within the feed pipe of the boiler, whether the latter received its supply from the heat savers or direct from the hot well of the engine, at least 100° colder. This result was evidently a consequence of the fact, that the quantity of heat required to raise the temperature of the water in the boiler about 100°, was practically nothing as compared to the quantity required to convert the same water into steam; if we may thus speak of heat by quantity, or as a substance, although it has not yet been either measured or weighed. At any rate, the results stated admit of no other explanation. And although we are quite aware that this is not in accordance with the received theory of heat, that is a matter for the chemist to reconcile. The only duty of an experimenter is to observe carefully, and state faithfully, the actual results of practice. And the engineer who, in advising on expensive undertakings, would allow his judgment to be warped from the evidence of facts by any preconceived theory whatever, must possess a larger share of veneration for great names and books than he has of conscientiousness or regard for the pecuniary interest of his employer. According to Dr. Black's great discovery, as it is called, of *latent* heat, we ought to save at least about *one tenth* of the fuel by plans analogous to those described above; but the facts are uniformly and without exception against such a result.

INVESTIGATION OF THE DIMENSIONS OF THE CYLINDRICAL BOILER WITH FLAT ENDS.

191. Having in previous chapters determined the necessary proportions in practice for the heating surface, fire-grate, and capacity for steam and water, we are now in a condition to investigate the dimensions that a boiler ought to have for any given number of horses power; and in order to free the problem from as much complication as possible in the first instance, we shall take the simple cylindrical low pressure boiler with flat ends:—

Let P = the horse power.
D = diameter of the boiler in feet.
L = length of ditto.
Also, let c = capacity per horse power in *cubic* feet.
s = the effective heating surface in *square* feet.
And $a = \cdot 7854 \times 2$ or $3\cdot 1416 \div 2 = 1\cdot 5708$.

Now although it is generally expedient to gather in the brick-work of the side walls a little below the level of the horizontal centre line of the boiler or axis of the cylinder, we may consider the heating surface so lost, as only equivalent to the effective heating surface of the vertical or flat ends of the boiler, which we shall not here take into account; therefore we may consider the total effective heating surface as equal to half the convex surface of the cylinder.

Then the circumference will be equal to

$$3\cdot 1416 \times \mathrm{D} = 2\,a\,\mathrm{D}.$$

$$\text{And half circumf.} = a\,\mathrm{D}.$$

Consequently $a\,\mathrm{D}\,\mathrm{L}$ = the area of the bottom convex surface, or effective heating surface in square feet.

And the horse power as it depends upon surface, will be this area ÷ by s, or

$$\mathrm{P} = \frac{a\,\mathrm{D}\,\mathrm{L}}{s} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Again, the area of the cross section of the boiler in square feet will be equal to

$$\cdot 7854 \times D^2 = \frac{a\,D^2}{2}$$

Therefore the capacity in cubic feet must be

$$\frac{a\,D^2\,L}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and the horse power as depends on capacity will be equal to this expression divided by c, or

$$P = \frac{a\,D^2\,L}{2\,c} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Consequently we have the following equation:—

$$\frac{a\,D^2\,L}{2\,c} = \frac{a\,D\,L}{s}$$

$$\text{or} \quad \frac{D}{2\,c} = \frac{1}{s}$$

Hence $$D = \frac{2\,c}{s} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

By which it appears that the value of D or the *diameter*, is independent of the *length* of the boiler, or of the horse power, but is constantly as the proportional values of c and s, or the proportion which we give to the heating surface as compared to the cubic capacity of the boiler.

From the equation $P = \frac{a\,D\,L}{s}$ we obtain

$$a\,D\,L = s\,P.$$

Hence $$L = \frac{s\,P}{a\,D} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Then if we take $c = 27$, and $s = 9$, and substitute these numbers in the expression for the value of D as before found, we shall have

$$\frac{2\,c}{s} = \frac{2 \times 27}{9} = \text{D} = 6 \text{ feet,}$$ for the constant diameter of all cylindrical boilers with these proportions.

Also $$\text{L} = \frac{9\ \text{P}}{1{\cdot}57 \times 6} = \frac{9}{9.42}\ \text{P} = {\cdot}955\ \text{P}.$$

Consequently ·955 feet, or 11½ inches nearly for each horse power, will be the length of the boiler between certain limits, dependent upon considerations respecting the length that it is expedient to allow the smoke to traverse in contact with the boiler, which have been the subject of Articles 175, &c., of this chapter, and which we shall again have to advert to.

192. The above determination gives a sufficient reason for the ordinary practical rule of the Lancashire boiler makers, when making cylindrical boilers without inside flues, in allowing about six square feet of water surface for each horse power, or in boilers of 6 feet diameter, to make them as many feet in length as they are intended to be horses power.

A rule to correspond exactly with the proportions of a square yard of heating surface to a cubic yard of capacity, will be $\cdot955 \times 6 = 5{\cdot}73$, or very nearly 5¾ square feet of water surface for each horse power.

193. Although the mode of measuring the power of a boiler by the *water* surface will always give us a correct proportion for the *heating* surface of the boiler, yet if the diameter be more than 6 feet, there will be more than a cubic yard of capacity or boiler room for each square yard of surface, and if less than 6 feet the contrary. Hence by using 5·73 as a constant divisor of the water surface, in all cylindri-

cal boilers of 2 yards wide, the result will always give us *exactly* the square yards of half the convex area, and at the same time very nearly one cubic yard of *internal* capacity for steam and water for each foot in length of the boiler.

The above coincidence between the even numerical results, and the results of experience, is a remarkable fact, and affords an additional reason for the propriety of adopting the cubic yard as one of the unit measures of steam boiler power.

194. The convenience to practical men of adopting round numbers as unit measures, when they come pretty near the actual values, in all results that only admit of being estimated, is so great, that many, perhaps, may be induced to suspect, that, in this case, we may have strained the facts a little on purpose to make them fit the rule. But we can assure our readers that the coincidence just mentioned did not occur to us until after the first edition of this work was printed, or otherwise we certainly would have mentioned it as an additional reason for adopting this particular proportion, as analogous coincidences were then stated, more particularly in the first chapter (Art. 5, 6.) And in the second edition it so happened that we had no opportunity of making either that or any other alteration. Besides it may be sufficient to state that general rules closely approaching the above, have been notoriously in use a great number of years, and the facts corresponding with them are easily proved and have been proved in hundreds of instances.

Although we highly value a simple methodical system of stating the combined results of calculation and observation, as being conducive to the most ready apprehension and easy application of all useful knowledge, we are certainly not such sticklers for mere methodism as knowingly to risk even the smallest deviation from truth, when the latter admits of correct ascertainment; but in physical problems of the nature of those now treated of, we are equally opposed to that absurd refinement in the use of figures that is too frequently to be found in the reports of some of the most eminent of our railway and other engineers, especially when they contain series of observations for the purpose of obtaining averages or striking a mean in the ordinary arithmetical way. This ultra exactness is a practice that is daily increasing, and may properly be called a sort of *scientific superstition*, for it practically produces more error than the actual errors of observation themselves are generally capable of doing*.

195. For the above as well as other reasons which could be adduced if necessary, we would respectfully urge the necessity of engineers generally sanctioning either this or some other plan equally feasible and convenient as a measure of steam boiler horse power. Like the steam engine horse power, it is not at all necessary that it should be an absolutely exact average of the power of a *living* horse, but as near an approach thereto, as to enable any one not conversant with the subject, to have a ready apprehension of its meaning as a *measure of force*, and at the same time a tolerably correct idea of the amount of power capable of being produced in the boiler indicated by it. For this purpose, it is also expedient, that whatever difference there is between the calculated *boiler horse power*, and the *real horse power*, the error should be in excess, as is the case with Watt's *steam engine horse power*, which is, as we have elsewhere stated, 150 lbs. lifted at the rate of 2½ miles an hour, or 33,000 lbs. lifted one foot per minute, and which, as every one knows,

* This may be easily proved by trying almost any of the numerous published reports of important experiments by the method of "least squares," when the useless exactness of minute fractions, while there are errors in the integers, becomes immediately evident.

is much more than the strongest horse can do for any considerable length of time. This standard for the steam engine horse power has been vainly endeavoured to be altered, but the comparative incongruity of all other measures that have been proposed have been at once seen and repudiated*. In the same way it will be found that the mode of estimating the power producing qualities of boilers by their cubic yards of capacity and square yards of surface, will equally in time be appreciated. And it may be mentioned that the object to be obtained by this uniformity of measurement is not altogether unimportant in a *statistical* point of view; the capacity being always the space the boiler occupies, while the surface will always bear a certain ratio to its weight and consequent expense.

196. It follows from what has been stated, that the correct, as well as the easiest method of measuring the heated surface of cylindrical boilers of any diameter, is to measure the area of water surface and divide it by $5\frac{3}{4}$, or more nearly 5·73; which will give us the exact area of the lower half of the convex surface in square yards; which, after deducting any portion that may be covered by brick-work of flues or otherwise, and adding such portion of the end vertical surface as may be considered *effective* heating surface, will represent an exact measure of the horse power of the boiler in any ratio of surface to horse power that may be required.

Hence we find the very near agreement with truth of the various common rules in use all over the north of England, for measuring the horse power of a boiler by water surface,

* Brunton's "*Compendium of Mechanics*," and Roberts' "*Mechanic's Assistant*," both state that Boulton and Watt's steam engine horse power is 32,000 lbs. instead of 33,000 lifted one foot high per minute; which is an error that we respectfully point out to the authors of those two very useful and original works, and the only works of the kind that the working mechanic, a very few years ago, could lay his hands on.

and which have been so much scouted by scientific men. We have before given examples of these rules as applied to the wagon boiler, (Art. 111,) in which five square feet of water surface is allowed for each horse power, which in the ordinary wagon-shaped boiler gives exactly one square yard of effective heating surface for each horse power, and the same result is obtained by applying a similar rule to cylindrical boilers, only substituting 5·73 instead of 5 for the divisor.

197. The following is a formula for half the convex area of a cylindrical boiler, which, as we have shewn, is also identical with the area of effective heating surface.

Slide Rule.

A	Diameter of boiler in feet.	Divisor 5·73.
B	½ Convex surface, or total effective heating surface in square yards.	Length of boiler in feet.

Example.

A	Diameter 5½ feet.	Divisor 5·73.
B	Convex surface 32 square yards.	Length 33½ feet.

EXPERIMENTAL CYLINDRICAL LOW PRESSURE BOILER.

198. The above example is that of a boiler now at work at Mayfield print works, in Manchester. It will be observed that the diameter is less than six feet, and of course the capacity is less than a cubic yard for each square yard of surface, but the exact proportion we can obtain from the equation (4), Article 190, which is

$$c = \frac{sD}{2} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

or $c = 9 \times 5\frac{1}{2} \div 2 = 24{\cdot}75$ cubic feet instead of 27 for each square yard of surface, and the total capacity will be

$24{\cdot}75 \times 32 \div 27 = 29{\cdot}33$ cubic yards. Consequently the boiler was considered to be about 30 horse power, and was accordingly provided with a fire-grate of $5\frac{1}{2}$ feet square, or $30\frac{1}{4}$ square feet area. But as it was not expected when this boiler was started in 1835 that so much as 30 horse power would be required from it, the area of the fire-grate was reduced in the first instance, by covering a portion of it with brick-work, to about 24 square feet, or *three quarters* of a square foot of grate to each horse power or square yard of surface. The real power of the boiler being then, by Formula 1, Art. 190, reduced to

$$\sqrt{32 \times 24} = 27{\cdot}7 \text{ horse.}$$

With the above proportions, the boiler was worked a few weeks, making an average evaporation of 29 cubic feet, and consuming 290 lbs. per hour of Lancashire coal of average quality, the rate of combustion being about 12 lbs. upon each square foot of grate per hour; the grate bars being $1\frac{3}{4}$ inch thick, and $\frac{1}{4}$ inch apertures between them.

199. Toward the end of the first month, attempts were made to burn the smoke upon Parkes's principle; that is, by keeping a very thick fire, and inflaming the smoke by letting in fresh air at the bridge of the furnace; which only partially succeeded when the evaporation was only required to be about 24 cubic feet. But as the quantity of steam wanted by the works fluctuated sometimes suddenly, up to 30 cubic feet and upwards per hour, it was found that it would not do at all as a smoke burner, although that system of heavy firing was persevered in for a few days, the average evaporation being 27 cubic feet and the consumption of coal having risen to about 11 lbs. per cubic foot. The necessities of the works however soon required a much greater evaporation than this, which was attempted by hard firing, and an excellent draught; but the steam could not be kept up, and a very slight injury was sustained by the boiler bottom from the intense action

of the flame, just in front of the centre of the bridge. The furnace was then enlarged to the full size of the fire-grate, or 30 square feet, and then with a fire nearly as thick as before we had about the same rate of combustion, the coal used being exactly 374 lbs. per hour when the evaporation was 36 cubic feet per hour, the ratio of consumption being thus reduced to little more than 10 lbs. per cubic foot.

200. The above experiments were made in August 1835, after the boiler had been about six weeks at work, and the last may be considered as the best effect that could be produced for a whole day together, but could not be kept up as an average, as it required careful firing and great attention, the steam requiring to be kept exactly at 4 lbs. per square inch, for at 4½ the water boiled over at the feed head, and at 3½ the engine went too slow. Although by heavy firing upon the front portion of the grate and letting in a little air at the furnace door, the very black smoke could be partly prevented, it required more attention than the average of firemen could be found to give, and was therefore given up, and the system of firing frequently and keeping a thin level fire was adopted; at the same time a few of the grate bars were taken out and the remainder equally spaced, so as to allow the apertures between them to average $\frac{5}{16}$ths of an inch each.

After the last alteration the boiler was worked regularly 77½ hours per week for upwards of six months continuously, with a consumption of coal varying from 4 to 5 cwt. per hour, the evaporation during that time being seldom so low as 33 cubic feet, and frequently 45 cubic feet per hour. Hence the average ratio of consumption was in the first case $448 \div 33 = 13 \cdot 5$ lbs., and in the latter $560 \div 45 = 12 \cdot 44$, or nearly 12½ lbs. of coal per cubic foot per hour. This consumption, as in the former experiment, of course, includes the whole of the coal used for getting up the steam, waste by keeping the fire in all night, &c.

201. We have been thus particular in stating the progress of the above experiment, because we paid constant attention to it during the whole of the winter of 1835-6, and because evaporation experiments are now becoming daily of increasing interest. And we give the details of *this one case*, so that any one may judge for himself as to all the circumstances that might influence the result, in preference to the more popular plan of giving a great number of cases and then taking an average, which, as regards steam boilers, from the great variety of circumstances affecting them, seldom fails in producing the most fallacious results. It is much to be regretted that most of the published statements respecting the performances of the Cornish engines, although elaborately drawn up and tabulated with apparent scientific minuteness, are almost useless for reference and comparison with the Lancashire practice, on account of the peculiar system of classification and reducing the averages. And without intending in the slightest degree to impeach the accuracy of the facts mentioned, or the motives that have induced their continual reiteration for several years past, it is impossible not to perceive that the manner in which they are usually stated entirely precludes the possibility of unqualified credence being given to them; they are too much akin to the prevailing practice of the political economists of our modern statistical societies, who by artfully classifying and striking *mean* averages are capable of making out reports favourable to almost any preconceived opinion whatever.

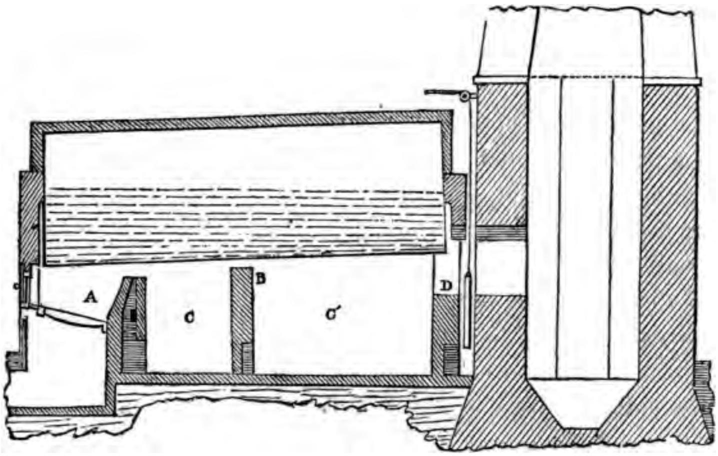
202. As an example in the statistics of steam, we shall now give a sketch of the boiler we have just been treating of, with all the necessary data for drawing just conclusions respecting it, as a specimen for our Cornish brethren,—not as a specimen of the best Lancashire practice, very far from it, but as an example of a fair and honest statement, which may perhaps draw out some similar statement

on the part of the Cornish practice from some practical engineer, independently of all scientific authority, (however unquestionable,) and also free from the certain bias which must necessarily prevail when an experiment is got up for the purpose. For these reasons, it will be sufficient to take the particular boiler noticed above, it being decidedly below the average of the Lancashire practice both in evaporating power and economy, although nearly equal in both those qualities to what is usually obtained in the particular kind of work that it is used for. It being of the kind now generally used at the various paper-making, bleaching and calico-printing works, as well as at many of the collieries throughout the cotton manufacturing district.

203. This boiler was purposely chosen of this simple and elementary form, and set up in the cheapest and simplest manner; that is, upon the "oven plan," so that all alterations or improvements that it might have been found expedient to make, either in the setting or the construction of the boiler itself, might be in the shape of *additions* merely, and therefore capable of being separately proved, both as to first cost and profit; and also that observations might be made upon it, for a sufficient length of time, without the liability to error arising from complication of construction, or interruption from the necessity of cleaning out flues or otherwise. It was thus made to answer the purpose of a trial boiler in order to guide the firm to which it belonged in their choice of what kind of boiler to adopt in the erection of new works then contemplated by them.

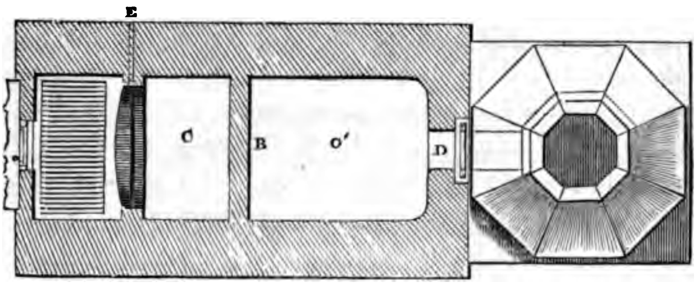
204. The following figure represents a longitudinal section through the centre of the boiler, furnace and chimney, in all respects proportional except as to length, which is to a scale of one-half of that for the depth and width, and fig. 17 represents a plan, or bird's-eye view, of the furnace, flame

Fig. 16.



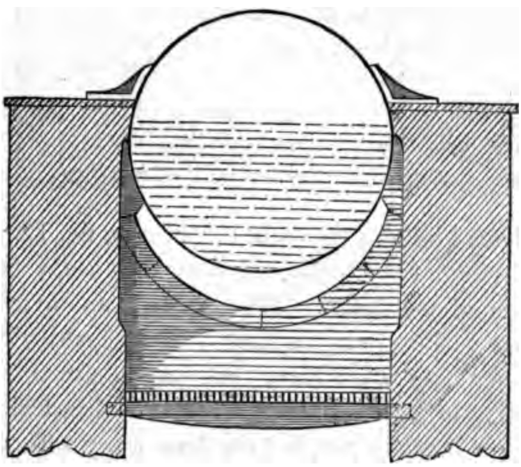
bed, chimney, &c., supposing the boiler to be removed; and the same letters refer to the same parts in both figures. The boiler is hung upon cast iron brackets, riveted to its sides a little above the centre, and with broad flanges resting upon the top of the side walls, as is shewn in the cross sections figures 18 and 19. It is fixed in an inclined position, or with a fall of about 8 inches to the front, so that by far the greatest proportion of the water is brought immediately over the furnace, as is shewn in figure 16. A is the fire-grate with the ordinary furnace bridge at the end of it, only that the latter is provided with a longitudinal aperture, about 2 inches wide, communicating by a channel at its bottom, with the external air at E, and provided with a valve, so that the smoke could be consumed upon Parkes's principle, if necessary. But in addition to this, there is also another bridge, B, at about half the length of the boiler, which divides the flame bed into two chambers C C′. The damper plate D, is hung by side rods in the short passage leading to the chimney, which is the only part that can be properly called a flue. The damper is inverted, or made to open downwards, so that the current of smoke or hot air is made to pass *over* instead of *under* it. The octagonal chimney is 30 yards high and 3 feet wide in-

Fig. 17.



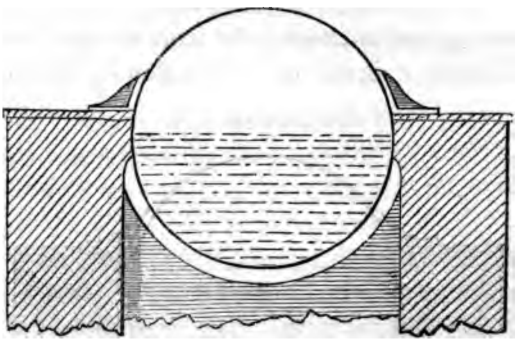
side at the top, and intended to be large enough for two such boilers, which it evidently is. The following cut (fig. 18) is

Fig. 18.



a cross section of the boiler taken through the furnace at A, just in front of the fire bridge. This bridge is an inverted arch of the same radius as the boiler, and placed 8 or 9 inches below the bottom of the latter. The second or *flame* bridge, B, is principally for the purpose of spreading the flame and heated air around the convex heating surface of the boiler in a stratum of comparatively equal thickness, and is considered an absolutely essential requisite when a boiler is set up upon the oven plan, and two or three such bridges are still more economical. They are usually called check bridges, from their tendency to check or impede the rapid current of hot air in its passage to the chimney, and consequently retain the heated gases longer under the boiler, which they certainly do, quite as effectually as causing the smoke to pass through long winding flues; but this is perhaps the least important purpose they subserve.

Fig. 19.



The flame bridge is shewn in elevation in fig. 19, which is a cross section of the boiler and flame bed at the middle of the length of the boiler. This bridge is an inverted arch about five inches from the boiler, and equally distant all round. We may state here, that proper attention to the construction of these bridges is a matter of considerable importance; sometimes people have done away with them altogether, and then an enormous waste of fuel ensues, the flame being then apt to divide itself into two currents, one on each side of the boiler, and thus run off to the chimney without taking much effect upon the boiler bottom; others again have gone into the other extreme, and built a continued inverted arch from the fire bridge to the end of the boiler, which we need hardly observe, hurries the heated gases too rapidly off to the chimney.

205. *Dimensions of Boiler.*—

Length 33 feet $8\frac{3}{4}$ inches }
Diameter 5 — $5\frac{1}{2}$ — } outside. One-half of the convex surface was wholly exposed to the direct action of the flame and hot air, except about 4 inches in depth all round along each side and across the ends, amounting to about 1 square yard. The quantity of water worked with was 15 cubic yards, which was kept uniformly supplied by means of the ordinary feed pipe and float; the temperature of the feed water being the same as that of the atmosphere.

Dimensions of Fire Grate.—

Length 5 feet 6 inches }
Breadth 5 — 6 — } clear within the bearing bears, and within the side walls of the furnace. Fire bars in one length, $1\frac{3}{4}$ inch thick, $\frac{5}{16}$ inch between each, and set sloping, or declining towards the bridge, so as to be 2 feet 8 inches from the boiler bottom at the back and 1 foot 11 inches at the front end of the grate.

The boiler was made by Mr. Fairbairn, of Manchester, with the best Low Moor iron $\frac{5}{16}$ thick. It supplied steam to a 16-horse engine, loaded so as to require never less than 24 cubic feet of water evaporated per hour, also steam for heating drying cylinders, boiling water, and a variety of other purposes, amounting at times to nearly as much as the engine required itself.

206. *Consumption of Fuel.*—The quantity of coal consumed from the 22d of March at two o'clock P.M. to the 7th of April at four o'clock P.M. (during which time the engine worked 242 hours) was 57 tons 10 cwt. 3 qrs., being about $4\frac{3}{4}$ cwt., or exactly $532\frac{1}{2}$ lbs. per hour. This of course was the *whole* of the

fuel used, from which (in order to compare with the Cornish system) it would only be fair to deduct 15 per cent. for waste and consumption during getting up the steam, more particularly as the boiler stood in an open yard quite exposed on all sides, and with merely a covering of a single brick in thickness, resting on the top of the boiler, and without double walls or any of the artifices usually resorted to for husbanding the heat; but to prevent the possibility of cavil upon this head, we shall take it at only 10 per cent., leaving 479¼ lbs. as the net hourly consumption while the boiler was at work; the rate of combustion being nearly 16 lbs. per square foot of grate. It is also necessary to add, that during this fortnight's trial, the fireman, who was only one of the ordinary labourers employed in other departments in the works, and not the engineer, was left entirely to consult his own ease in shovelling the coals into the fire, which I observed he did at periods varying from 6 to 10 minutes, no injunction whatever being laid upon him except that of keeping the steam up, and not to allow any to blow away to waste. Consequently we may safely calculate upon producing at least an equal effect under almost any conditions whatever.

207. *Water evaporated.*—The evaporation was taken frequently during the above period at different times of the day. The least evaporation ever required was 33 cubic feet per hour, and the highest was 45, the last being frequently made for several hours together.

The mode of taking the evaporation was by allowing the feed water to run into the boiler and fill it up 2 or 3 inches above the ordinary level, and then to stop off the feed until by evaporation the surface subsided to an equal distance below, when, by knowing the inside dimensions of the boiler, of course the quantity of water boiled away was ascertained to great exactness, and the time occupied (generally from one to two hours) noted. No such thing as a *correct* *water meter* for a steam engine boiler has yet been brought into use, but an efficient check upon the above method was afterwards tried at the same boiler by employing a man at the feed head, who actually measured the water from a cistern erected for that purpose.

TABLES OF DIMENSIONS AND PROPORTIONS OF LOW PRESSURE CYLINDRICAL BOILERS.

208. From the equation (4), Article 191, we obtain the following rule for all cylindrical boilers with flat ends:—Divide the cubic feet per horse power, by the square feet per horse power, and the quotient is half the diameter of the boiler: Hence a boiler of—

Cubic feet.	Sq. feet.		
33	÷ by 11 per H. P.	= 3	× 2 = 6 feet diam.
30	10	= 3	
27	9	= 3	
24	8	= 3	
21	7	= 3	
33	÷ by 12 per H. P.	= 2¾	× 2 = 5½ feet diam.
27½	10	= 2¾	
24¾	9	= 2¾	
22	8	= 2¾	
16½	6	= 2¾	
30	÷ by 12 per H. P.	= 2½	× 2 = 5 feet diam.
27½	11	= 2½	
25	10	= 2½	
22½	9	= 2½	
20	8	= 2½	
27	÷ by 13½ per H. P.	= 2	× 2 = 4 feet diam.
24	12	= 2	
20	10	= 2	
18	9	= 2	
12	6	= 2	

Cubic feet.		Sq. feet.			
24	÷ by	16 per H. P.	=	$1\frac{1}{2}$	× 2 = 3 feet diam.
21	……	14	=	$1\frac{1}{2}$	
18	……	12	=	$1\frac{1}{2}$	
$13\frac{1}{2}$	……	9	=	$1\frac{1}{2}$	
9	……	6	=	$1\frac{1}{2}$	
$22\frac{1}{2}$	÷ by	18 per H. P.	=	$1\frac{1}{4}$	× 2 = $2\frac{1}{2}$ feet diam.
15	……	12	=	$1\frac{1}{4}$	
$11\frac{1}{4}$	……	9	=	$1\frac{1}{4}$	
10	……	8	=	$1\frac{1}{4}$	
12	÷ by	12 per H. P.	=	1	× 2 = 2 feet diam.
9	……	9	=	1	
6	……	6	=	1	

The above tablets will be found useful for boiler makers to refer to, when about to make cylindrical boilers of any of those proportions, and which include all that are ever likely to be wanted. When the diameter is thus fixed on, the length for any horse power may be found from the rule in the next article.

209. From the equation (5), for the length of the boiler (Article 191), we have the following rule:—Multiply the horse power of the boiler, by the square feet of heating surface per horse power, then divide this product by 1·57 times the diameter, and the quotient is the proper length of the boiler in feet, for the given horse power; such boiler having that proportion of capacity to surface, which is found with the corresponding diameter, in the preceding article.

210. This rule put into a formula for the slide rule will stand as follows:—

A	Length.	Sq. feet of heating surface per H. P.
B	Horse power.	Diameter × 1·57.

Example.—Suppose the diameter of the boiler is $5\frac{1}{2}$ feet, the divisor for that diameter will be $5\frac{1}{2} \times 1{\cdot}57 = 8{\cdot}63$; then if we suppose the area of the heating surface per horse power to be 9 square feet, and consequently the capacity of the boiler will be (Art. 208) $24\frac{3}{4}$ cubic feet per horse power, then will the line B represent a series of boilers of various powers, and the line A the corresponding lengths of those boilers respectively, as follows:—

A	Length	24	37½	50.	Area of heating surface = 9.
B	Horse power	23	36	48.	Divisor .... = 8·63.

211. By the use of this formula, the following tables were calculated purposely for the use of boiler makers, who will find in them, by inspection, the *horse power* and corresponding *lengths* of all the usual sizes and proportions of low pressure cylindrical boilers, without inside flues; and any other size or proportion, not in the tables, can be easily obtained by the same means, or more exactly by the arithmetical rule, Article 209.

Mechanics have long been in possession of what is called the "Millwright's Table," therefore we have ventured to designate the following the *Boiler-Maker's Tables*, and which we hope will be found equally useful for reference, not from any presumed difficulty in the calculation, as that is but trifling, but for the convenience of having a great number of calculated results presented to the eye at once; a plan which is always found to be of considerable assistance in facilitating decision on the choice of a boiler for any particular situation, among several that are nearly about equally eligible. These Tables it is also presumed, will not be without their use to the Factory Architect and Engineer, who sometimes allow the boilers to be placed in any out-of-the-way corner that *they* think is fit for nothing else, or as a matter of little importance; the consequence too frequently is, that the boilers are obliged to be stowed away under ground in order to get sufficient room,—hence the usual but too true term, the "Fire-hole." There can, however, now be no excuse for planners of factories, if they give rise to the almost constant complaints of want of boiler-room. The dimensions in the fourth column of Table 1, will be found amply sufficient for all other kinds of land boilers, as well as cylindrical ones; for the latter those in the third column are sufficient, and for reasons which we have frequently given in the course of this work, generally to be preferred.

212. *Boiler-Maker's Tables:*—The first seven of the following Tables are for the purpose of finding the lengths in feet of low pressure cylindrical boilers of various diameters (without inside flues), and of various proportions of heating surface and capacity for each horse power from the equation (5), Article 191, which is

$$L = \frac{s P}{a D};$$

the value of a D, or 1·57 times the diameter, being the divisor by which the length can be found for any number of horses' power not comprised in the Tables, as directed in Articles 209, 210.

Also, $s =$ the heating surface in square feet, and $c =$ the capacity in cubic feet for each horse power.

TABLE 1.

Diameter ...... 6 feet.
Divisor .... 9·42.

Horse power.	LENGTH OF BOILER IN FEET.			
	$s=8$ $c=24$	$s=9$ $c=27$	$s=10$ $c=30$	$s=11$ $c=33$
40	34	38	42	47
38	32	36	40½	44½
36	30½	34	38	42
34	28½	32½	36	39½
32	27	30½	34	37
30	25½	28½	32	35
28	23½	26½	29½	32½
26	22	24½	27½	30
24	20½	23	25½	28
22	18½	21	23½	25½
20	17	19	21	23½

In using the above Table, it must be borne in mind that two boilers, say for instance two of 20 horse power each, are not necessarily equally eligible with one of 40 horse power, in respect of economy, although of equal power. The economy depends entirely upon the mode of setting up, for which see Articles 180, 181, and the four general rules in Article 183.

TABLE 2.

Diameter ...... 5½ feet.

Divisor .... 8·63.

Horse Power.	LENGTH OF BOILER IN FEET.			
	$s=6$ $c=16\frac{1}{2}$	$s=8$ $c=22$	$s=9$ $c=24\frac{3}{4}$	$s=10$ $c=27\frac{1}{2}$
40	28	37	42	46
38	26½	35	39½	44
36	25	33½	37½	42
34	23½	31½	35½	39½
32	22	29½	33½	37
30	21	27½	31	34½
28	19½	26	29	32½
26	18	24	27	30
24	16½	22	25	27½
22	15½	20½	23	25½
20	14	18½	21	23

TABLE 3.

Diameter ...5 feet.

Divisor ......7·85.

Horse Power.	LENGTH OF BOILER IN FEET.			
	$s=6$ $c=15$	$s=8$ $c=20$	$s=9$ $c=22\frac{1}{2}$	$s=10$ $c=25$
40	30½	41	46	51
38	29	39	43½	48½
36	27½	37	41½	46
34	26	35	39	43½
32	24½	33	36½	41
30	23	30½	34½	38
28	21½	28½	32	35½
26	20	26½	30	33
24	18½	24½	27½	30½
22	17	22½	25½	28
20	15¼	20½	23	25½
18	13¾	18½	20¾	23

TABLE 4.

Diameter ...4 feet.

Divisor......6·28.

Horse Power.	LENGTH OF BOILER IN FEET.			
	$s=6$ $c=12$	$s=8$ $c=16$	$s=9$ $c=18$	$s=10$ $c=20$
36	34½	46	52	58
34	32½	43½	49	54½
32	30½	41	46	51
30	28½	38	43	48
28	27	35½	40	45
26	25	33	37	41½
24	23	30½	34	38
22	21	28	31½	35
20	19	25½	28½	32
18	17¼	23	26	29

213. The next three Tables contain proportions that are almost impracticable, if used for boilers, but they are inserted because they may be found useful in estimating the value in horse power of inside flues.

TABLE 5.

Diameter, 3 feet. *Divisor*, 4·71.

Horse Power.	LENGTH OF BOILER IN FEET.		
	$s=6$ $c=9$	$s=9$ $c=13\frac{1}{2}$	$s=12$ $c=18$
30	38	57	76
28	35½	53½	71
26	33	49½	66
24	30½	45½	61
22	28	42	56
20	25½	38	51
18	23	34½	46
16	20½	30½	41

TABLE 6.

Diameter, 2 feet. *Divisor*, 3·14.

Horse Power.	LENGTH OF BOILER IN FEET.		
	$s=6$ $c=6$	$s=9$ $c=9$	$s=12$ $c=12$
20	38	57	76
16	30½	45½	61
12	23	34	46
11	21	31½	42
9	17	25½	34
7	13½	20	26½
5	9½	14	19

TABLE 7.

Diameter ...... 1 *foot.*
Divisor......... 1·57.

Horse Power.	LENGTH OF BOILER IN FEET.		
	$s=6$ $c=3$	$s=9$ $c=4\frac{1}{2}$	$s=12$ $c=6$
5	19	28½	38
4	15	23	30½
3	11½	17	23
2	7½	11½	15
1	3¾	5¾	7½
½	2	3	4

214. From what is before stated, there will not be the least difficulty in applying the above Tables to practical use for the particular kind of boilers they are meant for, that is, plain cylinders without inside flues.

The first *four* Tables contain the dimensions of all that are likely to be wanted in any case, if not the first *two;* and perhaps the first Table alone contains all that ought to be recommended generally, but they are all inserted here for the purpose of ready reference in estimating roughly the horse-power of any boiler we may meet with, whether of good or bad proportions, while the exponential letters s and c for surface and capacity, at the top of each column, indicate what those proportions are.

215. *Boiler maker's Tables for flued boilers.*—Tables 5, 6, and 7, besides containing the dimensions of small high pressure boilers that are most frequently to be met with, also serve to indicate roughly the value of inside flues:—

Thus, if we have a boiler of 6 feet in diameter, and 19 to 20 feet long, we shall find by Table 1, column 3, that in order to have 9 square feet of effective surface to 27 cubic feet of capacity for each horse, it will be about 20 horse power; but suppose it contains a cylindrical flue of 2 feet diameter, then look into the Tables for boilers of 2 feet diameter, which is Table 6, and we there find the length in the column for 9 feet of surface per horse, which is column 3, opposite to which is 7 horse power, for the value of the flue, consequently 27 horse is the power of this boiler, so far as depends upon heating surface. But so far as the power of the boiler depends on capacity, of course it is *diminished* by the capacity of the flue, which appears from the proportion stated at the head of the column to be only at the rate of 9 cubic feet, or $\frac{1}{3}$ of a cubic yard per horse power, therefore we must deduct one-third of seven horse power from twenty, leaving nearly 18 horse power for the boiler, so far as depends on capacity.

216. Now it is evidently of no consequence in considering the combined power of two boilers, whether they are placed alongside each other or end to end, or one inside the other, for in the latter case, that is, when the smaller boiler becomes a flue, the fire only acts upon the upper half of the internal instead of the lower half of the external surface. Therefore in all cases of boilers containing inside flues, the latter may be calculated as separate boilers from the shell or external case, and the horse power of the compound boiler will always be equal to the sum of that of both boilers so far as depends on surface, and to their difference so far as depends on capacity, and this principle forms the foundation for the Tables for flued boilers.

217. The above computation is sufficient to shew the manner in which the power of a flued boiler may be roughly

estimated by inspection of the foregoing Tables, when it is within the range of dimensions and proportions they contain; but for an exact evaluation of the powers of those boilers more extensive Tables are necessary, specimens of which we shall give, abstracted from larger ones which we expressly constructed and arranged, and have long used for this purpose. These Tables include nearly all the sizes of flued cylindrical boilers that are now made by the best makers for factory engines; and by means of the various simple formulæ for the slide rule in Articles 220, 221, or the arithmetical rules in the next Article, by which we originally calculated them, they admit of being very easily extended to all sizes and proportions whatever.

218. The Tables 8 and 9 are calculated in square yards of effective heating surface and cubic yards of total capacity, without any reference to the horse-power, which latter may be in any other proportion besides that which we have recommended. But assuming for the present that this particular measure of surface and capacity is also the measure of a boiler horse-power, the tables are thus used:—Suppose we have a cylindrical boiler of 32 feet long and 9 feet diameter and we wish to put a flue into it of such dimensions as will keep it in the proportions mentioned; we first find in Table 8, in the vertical column for 9 feet diameter, opposite to 32 feet in the left-hand column for lengths, that the effective heating surface and the total capacity are 50 square yards and 75 cubic yards respectively, and that the difference between these two numbers is 25, which is in the same square, but in the horizontal line of figures marked "dif." Now this difference is the guide or index number to point out the proper flue in Table 9. This flue we will suppose to be of the same length as the boiler itself; we therefore look for it in the horizontal column for flues of 32 feet long, and in the lower line of figures in that column, marked

"sums," we find our index number 25 in the vertical column for flues of 36 inches diameter, which is the size of the flue required. At the upper corners of the same square we have also the numbers 17 and 8 representing the surface and capacity of this flue in the same denominations as those of the boiler, the sum of which is the same as the index before found. The first of these numbers being added to and the second subtracted from the numbers before found for the boiler, give us the horse-power of the complete flued boiler as follows:

	ft.		ft.		sq. yds.		cub. yds.
Boiler......	32	by	9,	surface	50,	capacity...	75
Flue........	32	by	3,	do............	17,	do.	8
					—		—
Horse-power				....	67	....	67

Arithmetical rule.—The heating surface the same as in the Tables may also be found by multiplying the length of the boiler in feet by its diameter, and dividing the product by 5·727, the quotient is the surface in square yards.

The cubic content or capacity is found by multiplying the length by the *square* of the diameter, and dividing the product by 34·436 for *cubic* yards, as in Tables 8 and 9, or by 27 for *cylindrical* yards, as in Tables 10 and 11.

TABLE 8.

The areas of effective heating surface in *square yards*, and capacities in *cubic yards*, of cylindrical boilers adapted for inside flues.

Divisor for Surface......... 5·73.
Gauge point for Capacity.. 5·86.

Length of boiler in feet.	DIAMETER OF BOILER IN FEET. 7		7½		8		8½		9	
	Sq. yds.	Cub. yds.	Sq. yds.	Cub. yds.	Sq. yds.	Cub. yds.	Sq. yds.	Cub. yds.	Sq. yds.	Cub. yds.
20	24	28	26	33	28	37	30	42	31	47
dif.	4		7		9		12		16	
22	27	31	29	36	31	41	33	46	35	52
dif.	4		7		10		13		17	
24	29	34	31	39	33	44	36	50	38	56
dif.	5		8		11		14		18	
26	32	37	34	42	36	48	38	54	41	61
dif.	5		8		12		16		20	
28	34	40	37	45	39	52	42	59	44	66
dif.	6		8		13		17		22	
30	37	43	39	49	42	56	45	63	47	71
dif.	6		10		14		18		24	
32	39	45	42	52	45	59	48	67	50	75
dif.	6		10		14		19		25	
34	41	48	44	55	47	63	50	71	53	80
dif.	7		11		16		21		27	
36	44	51	47	59	50	67	54	75	57	85
dif.	7		12		17		21		28	
38	46	54	50	62	53	71	57	80	60	90
dif.	8		12		18		23		30	
40	49	57	52	65	56	74	59	84	63	94
dif.	8		13		18		25		31	

TABLE 9.

The areas of effective heating surface in *square* yards, and capacities in *cubic* yards of flues adapted to the boilers in Table 9.

Divisor for surface .... 5·73
Gauge point for capacity .... 5·86

Length of flue in feet.	DIAMETER OF FLUE IN INCHES. 12		18		24		30		36	
	Sq. yds.	Cub. yds.	Sq. yds.	Cub. yds.	Sq. yds.	Cub. yds.	Sq. yds.	Cub. yds.	Sq. yds.	Cub. yds.
20	3	0	5	1	7	2	9	4	10	5
sums.	3		6		9		13		15	
22	4	0	6	1	8	3	10	4	11	6
sums.	4		7		11		14		17	
24	4	0	6	2	8	3	10	4	13	6
sums.	4		8		11		14		19	
26	5	1	7	2	9	3	11	5	14	7
sums.	6		9		12		16		21	
28	5	1	7	2	10	3	12	5	15	7
sums.	6		9		13		17		22	
30	5	1	8	2	10	3	13	5	16	8
sums.	6		10		13		18		24	
32	6	1	8	2	11	4	14	6	17	8
sums.	7		10		15		20		25	
34	6	1	9	2	12	4	15	6	18	9
sums.	7		11		16		21		27	
36	6	1	9	2	13	4	16	7	19	9
sums.	7		11		17		23		28	
38	7	1	10	2	13	4	17	7	20	10
sums.	8		12		17		24		30	
40	7	1	10	3	14	5	17	7	21	10
sums.	8		13		19		24		31	

TABLE 10.

The areas of effective heating surface in *square* yards and capacities in *cylindrical* yards, of cylindrical boilers adapted for inside flues.

Divisor for surface .... 5·73
Gauge point for capacity .... 5·2

Length of boiler in feet.	DIAMETER OF BOILER IN FEET. 5		5½		6		6½		7	
	Sq. yds.	Cyl. yds.	Sq. yds.	Cyl. yds.	Sq. yds.	Cyl. yds.	Sq. yds.	Cyl. yds.	Sq. yds.	Cyl. yds.
16	14	15	15	18	17	22	18	26	19	30
dif.	1		3		5		8		11	
18	16	17	17	21	19	25	20	29	22	34
dif.	1		4		6		9		12	
20	17	19	19	23	21	28	23	32	24	37
dif.	2		4		7		9		13	
22	19	21	21	25	23	30	25	36	27	41
dif.	2		4		7		11		14	
24	21	23	23	28	25	33	27	39	29	45
dif.	2		5		8		12		16	
26	23	25	25	30	27	36	29	42	32	49
dif.	2		5		9		13		17	
28	24	27	27	32	29	39	32	46	34	53
dif.	3		5		10		14		19	
30	26	29	29	35	31	42	34	49	37	57
dif.	3		6		11		15		20	

TABLE 11.

The areas of effective heating surface in *square* yards, and capacities in *cylindrical* yards, of inside flues adapted to the Boilers in Table 10.

Divisor for surface .... 5·73
Gauge point for capacity .... 5·2

Length of flue in feet.	DIAMETER OF FLUE IN INCHES. 15		18		21		24		27	
	Sq. yds.	Cyl. yds.	Sq. yds.	Cyl. yds.	Sq. yds.	Cyl. yds.	Sq. yds.	Cyl. yds.	Sq. yds.	Cyl. yds.
16	3	1	4	1	5	2	6	2	6	3
sums.	4		5		7		8		9	
18	4	1	5	2	5	2	6	3	7	4
sums.	5		7		7		9		11	
20	4	1	5	2	6	2	7	3	8	4
sums.	5		7		8		10		12	
22	5	1	6	2	7	3	8	3	9	4
sums.	6		8		10		11		13	
24	5	1	6	2	7	3	8	4	9	5
sums.	6		8		10		12		14	
26	6	2	7	2	8	3	9	4	10	5
sums.	8		9		11		13		15	
28	6	2	7	2	8	3	10	4	11	5
sums.	8		9		11		14		16	
30	7	2	8	3	9	4	10	5	12	6
sums.	9		11		13		15		18	

219. From the above example it will be perceived that the reverse result may be almost as readily obtained by an inspection of the Tables; that is, the dimensions of a boiler to suit any given size of flue; and also both the latter may be found to suit any given horse-power, and one of the dimensions of the boiler may be given if required, as in the following—

Example. Suppose we want to make a flued boiler of 50 horse-power and of 8½ feet diameter, we must look down the column for that diameter in Table 8 until we find the nearest boiler with a suitable flue in the corresponding column of Table 9, which is that for 26 feet long, and the particulars of which are below:

	Ft.		Ft.		Sq. yds.		Cub. yds.
Boiler	26	by	8½,	surface......	38,	capacity......	54
Flue	26	—	2½,	do.	11,	do.	5
					—		—
				Horse-power	49	....	49

Now here, although the exact result for 50 horse-power is not obtained at once, it arises from the Tables only being calculated to the nearest whole numbers for each two feet in length, and the difference can be easily allowed for. In the above example, if we examine the next square below in the same manner, we shall find it to give the result of 54 horse-power, or 5 more for a boiler two feet longer, being at the rate of nearly 5 inches for each additional horse-power; hence the corrected length of the boiler will be 26 feet 5 inches for 50 horse-power.

220. The theory of the construction of these Tables will be readily understood if we refer to the equations in article 191, from which we obtain $\frac{a\,D\,L}{9} =$ the area of the effective heating surface in square yards or—

$$\frac{1{\cdot}5727\ D\ L}{9} = \frac{D\ L}{5{\cdot}727}$$

Also that $\frac{a\,D^2\,L}{54}$ = the capacity in cubic yards, or

$$\frac{1{\cdot}5727\,D^2\,L}{54} = \frac{D^2\,L}{34{\cdot}436}$$

From these two expressions we derive the following formulæ for the slide rule, by which Tables 8 and 9 were recalculated.

FORMULA 1. FOR SURFACE.

A	Divisor 5·727	Diameter in feet.
B	Length in feet	Surface in sq. yds.

The next formula is derived from the algebraical expression in exactly the same way, but as the square of the diameter is one of the factors, it is more convenient to use the diameter itself on the line D; and instead of the divisor 34·436, its square root 5·86 may also be used on the line D for a gauge point, as below:—

FORMULA 2. FOR CAPACITY.

C	Length in feet	Capacity in cubic yds.
D	Gauge point 5.86	Diameter in feet.

221. Tables 8 and 9 are calculated by the above two formulæ, and the surfaces in Tables 10 and 11 are also calculated by formula 1; but the capacities in the last two Tables being different, they required a different gauge point, which is obtained by reducing the divisor (34·436) in the original expression for the capacity in *cubic* yards, in the proportion of 1 to ·7854; the divisor then being a whole number, the expression becomes extremely simple, it is then

$$\frac{D^2\,L}{27}$$

and is well calculated for an arithmetical rule*, and the square root of this new divisor, 5·196 (say 5·2) is the gauge point for cylindrical yards to be used in the same manner as before, namely:—

* The rule in words, is to multiply the square of the diameter by the length, and divide by 27, and the quotient is the cubic contents of the boiler in *cylindrical* yards. A cylindrical yard is 27×·7854=21.2 cubic feet; and although we consider it too little, it is about the proportion of boiler room per horse power used by many engineers, hence the usefulness of a ready arithmetical rule for it. Moreover, as the use of circular dimensions in measuring circular things, such as boilers and cylinders, is so much more preferable and natural than the usual way of multiplying them by ·7854 in order to reduce them to square measure; and as it has always been so much approved by practical mechanics, we cannot avoid endeavouring to extend so useful a practice by recommending a method of squaring certain fractional numbers mentally, which we have long used and found a great convenience. It is no doubt well known to the teachers of mental arithmetic. It has been called, although somewhat inappropriately,

The Rule of squaring by halves.

To multiply $3\frac{1}{2}$ by $3\frac{1}{2}$, we say 3 times 4 is 12, and add a quarter, makes $12\frac{1}{4}$, which is the square of $3\frac{1}{2}$. In like manner to square $4\frac{1}{2}$, we say 4 times 5 is 20, and add $\frac{1}{4}$ as before, which makes $20\frac{1}{4}$. Thus always multiplying together the whole number *above* and the whole number *below* the fractional number to be squared, and then adding the constant fraction $\frac{1}{4}$ to the product. This rule is easily retained in the memory, and its use may be illustrated by application to the rule for boilers in the text; for instance, a boiler $5\frac{1}{2}$ feet diameter has $5\frac{1}{2}$ squared, or $5\times6+\frac{1}{4}=30\frac{1}{4}$ cylindrical yards capacity, provided it is 27 feet long, and of course at $13\frac{1}{2}$ feet long, it has $15\frac{1}{8}$ cylindrical yards, and so on. When *cubic* yards is the measure wanted, then the other divisor 34·43 is the length to be used; thus with that length, a boiler of $6\frac{1}{2}$ feet diameter contains $6\times7+\frac{1}{4}=42\frac{1}{4}$ cubic yards. Numerous other useful applications of this rule occur daily to the practical engineer, in estimating the strength of beams, ropes, &c., proportioning steam and water-pipes, estimating the weight of stones, &c.

FORMULA 3.

C	Length in feet	Cylindrical yards capacity.
D	Gauge point 5·2	Diameter in feet.

EXAMPLES IN USING THE TABLES.

222. *Ex.* 1. Required the size of flue, and the horse power of a cylindrical boiler 22 feet long by 6½ feet diameter, allowing a square yard of surface and a cylindrical yard of capacity for each horse power?

Answer. In the Tables 10 and 11 we find the—

	Feet	Feet.		Sq. yds.		Cyl. yds.
Boiler	22 by	6½,	surface......	25,	capacity	36
Flue	22 —	2,	do.	8,	do.	3
Horse-power			....	33	....	33

Ex. 2. Suppose that a boiler of the same external dimensions as the last is required to have two small inside flues instead of one large one, and retain the same proportions of surface and capacity, required their dimensions and the horse power of the boiler?

Answer. Here we take half the index number, or 5½, which would take us a little beyond the range of the Table, the lowest sum for that length of flue being 6, and the diameter 15 inches, therefore about 14 inches will be nearly the diameter required, and the result will stand as follows:

	Feet.			Sq. yds.		Cyl. yds.
Boiler......	22 by	6½ feet,	surface....	25,	capacity........	36
2 flues	22 —	14 inches,	do...........	4¾,	do	¾
	22 —	14 do......	do...........	4¾,	do.	¾
				9½	....	1½
Horse-power			....	34½	....	34½

Now, in setting up a boiler of this kind in the common way with side flues, of course the two seating walls take up a portion of the area of the bottom surface, which is not taken into account in the above calculation; but it can be easily made up for by carrying the walls of the side flues so much farther up, or quite to the level of the centre of the boiler, the surface of the water being, on account of the flue, so much higher.

Ex. 3. Suppose a fire box boiler of 30 feet long and 9 diameter is to have 3 flues, each 24 feet long, required the dimensions and horse power, allowing a *cubic* yard of capacity and square yard of surface per horse; and supposing the sides, &c., of the fire box to add as much to the capacity and surface of the boiler as it takes away?

Answer. By inspecting Table 8 we find 24 to be the index number, of which we take the third, or 8, and seek it in Table 9, among the flues of 24 feet long, where it is found under those of 18 inches diameter as follows:—

	Feet.	Feet.		Sq. yds.		Cub. yds.
Boiler	.......30 by	9,	surface	47,	capacity	71
3 flues	......24 —	$1\frac{1}{2}$,	do...	$3 \times 6 = 18$,	do.....$3 \times 2 =$	6
Horse power			....	65	....	65

CIRCULAR BOILERS IN STEAM PACKETS.

223. We have been induced to extend the consideration of the dimensions and proportions of the cylindrical boiler, not from any expectation that it will ever supersede the wagon-shaped form, as applicable to the low pressure Boulton and Watt land engine, but because as the practice of working engines to some extent expansively, and consequently at a higher pressure, is sure to prevail in some situations where

fuel is expensive, the cylindrical form will no doubt come more generally into use: and where high pressure non-condensing engines are obliged to be used, this boiler with hemispherical ends becomes absolutely indispensable.

Moreover the facility with which this kind of boiler can be made, is a great inducement for cheap boiler makers to recommend it in preference to all others, just as we find cheap engine makers frequently recommending high pressure engines, in which unskilful workmanship is so easily made up for by a little more pressure; it is therefore the more necessary that rules for obtaining the best proportions should be attended to.

224. That cylindrical boilers, or a form approaching thereto, will eventually be generally adopted in steam packets, scarcely admits of a doubt; for whether the increasing number of accidents arising from the bursting of marine boilers cause some governmental regulations to be enforced or not, it is certain that the owners of steam packets will sooner or later find sufficient reason to adopt such form of boiler as is most permanently conducive to their own interests, and those interests are of course best secured by the avoidance of all risk of danger to life and property.

Now it is a fortunate circumstance that the safest and strongest marine boiler that has yet been adopted is at the same time the most economical. We allude to the circular marine boiler with several tubular flues; it is a modification of Mr. Booth's locomotive boiler, but with the tubes of 10 to 15 inches instead of three inches diameter, and made to *return* once over the top of the main or furnace flues to the chimney, which is fixed near the front end of the boiler.

225. We were the first to recommend this kind of boiler to the notice of the boiler makers and engineers in Lancashire, immediately after the success of Mr. Booth's boiler, on

the Liverpool and Manchester railway. And although since that time we have never ceased to urge its general adoption, but particularly for steam packets carrying passengers, such is the inveterate conservative spirit of the managers and engineers of most Steam Packet Companies, and so determined is their opposition to the least inroad being made upon the old beaten track they have been used to, that comparatively very few have yet got into use. A bigoted adherence to old established plans is the greatest hindrance that at present exists to improvement in steam navigation. This opposition is not generally found amongst the workmen, who are usually sufficiently alive to the importance and necessity of adopting every real improvement in the present progressive state of steam navigation; it belongs altogether to the under managers, or "men in office"; and it is the more to be regretted that this disinclination to move onward, although masked under an appearance of prudential regard for their employers' interests, when examined into, is almost always found to arise from some vague and undefinable fear of some possible unforeseen trouble to themselves individually,—the real *vis inertiæ* of being well off and "let well alone,"—the all pervading disease of the servants and managers of most large companies.

226. To the enlightened directors and managers of the Dublin Steam Packet Company, however, the public is indebted for the only extensive introduction of the kind of boilers above described, that company having now several very large vessels furnished with them, some of them having been in constant service for years with unvarying success; amongst which we may mention the "Royal William" as having been recently on the New York station.

When we speak of these marine boilers as *cylindrical*, the expression is not quite correct, as very few have been made that are exactly circular in section; they are more generally a sort of oval; but the inside flues, with the exception of the furnace, are uniformly cylindrical. They are generally called *circular boilers;* which is, perhaps, sufficiently characteristic of their form; the top and bottom of the outer shell, as well as nearly all the internal parts, being described by arcs of circles.

THE RIVETING MACHINE.

227. It is indisputable that the circular marine boilers, if properly proportioned, are at least fully as economical as the ordinary square form with continuous winding flues; and if equally well made, are decidedly stronger, and consequently safer; and we are going to shew that they not only admit of being quite as well made, but a great deal better than the old square form. This arises from the peculiar facility with which the plates of all kinds of circular work admit of being riveted by means of the *riveting machine.*

We consider that the invention of this machine bids fair to create a new era in the practice of boiler making; and the very liberal manner in which it has been introduced to the trade generally, by the inventors and proprietors, Messrs. Fairbairn and Co., the well known eminent engineers of Manchester, and of Blackwall, London, is deserving of the highest encomiums. Protected by the monopoly of a patent, they were fairly entitled to the exclusive use of the machine to their own great and manifest advantage; instead of which they liberally supply it to all who wish to take advantage of it.

228. The various machines already well known to boiler makers for *punching* the rivet holes in the plates, and for *bending* the latter to the proper form, together with the recent addition of the riveting machine, now form a complete system of what Dr. Ure would call automatic machinery,

that is unequalled for simplicity, power, and efficiency, and impossible to be surpassed in importance. At Mr. Fairbairn's works, a boiler of considerable size has been made in *one day* by the assistance of this machine; and with the exception of closing in the ends (which of course requires to be done by hand) entirely *without noise;* which latter peculiarity is of no small importance in the centre of a large town, such as is the situation of Mr. Fairbairn's Manchester works.

The impossibility of overrating the importance of this invention will be at once manifest, when we state that it has already rendered two establishments in Lancashire capable of turning out between them a boiler per day of almost any required power; which assertion, if it had been uttered three years ago, as a prediction of something within the range of future possibilities, would have been treated as the wildest romance. The other establishment which we have alluded to as having a riveting machine at work is the Soho iron-works and steam-engine manufactory of Benjamin Hick, Esq. of Bolton. There are also many other establishments to which Messrs. Fairbairn and Co. are supplying the machines, and which will probably be at work before this account is printed.

229. In a national point of view, and particularly in the aid which will be afforded by this machine in supplying safe high-pressure boilers to our future steam navy in case of war, the subject is of intense interest. Great as were the important discoveries of the French chemists in the manufacture of gunpowder at the period of the revolution, they sink into insignificance when compared to the improvements by English mechanics during the last ten years, not in steam machinery alone, but in *tools for making machinery.* The amazing facilities of production brought about by the various recent modifications of the planing machine, (of which the millwrights of twenty years ago were entirely ignorant,) are a sufficient warrant for this assertion. And it is not too

much to say, that the two engineering establishments above mentioned, by a highly judicious selection and application of the modern improvements in machine-making tools, are now capable of turning out steam-engines and boilers to a greater amount of power in an equal space of time, than the whole of England besides could have produced a quarter of a century ago. In addition to this, when we consider the modern resources of *iron* ship-building, a business which has been extensively carried on by Messrs. Fairbairn and Co. for several years, we shall not have to regret much the decay of our "*wooden* walls" in the event of another war*.

230. If the results obtainable by the riveting machine were those exclusively or principally relating to dispatch only, at the expense of producing a less perfect article, the above encomiums would be perfectly unwarranted; but the fact is, that the execution of the work, like that produced by the planing machine, is superior in every respect to that effected by hand labour. That the superiority of both these machines in this respect are alike dependent upon principles connected with a new process, and not as in our numerous French and American patent *pin making*, *card making*, and spinning machines, a complicated, and consequently feeble and ineffectual imitation of manual operations, it would not be difficult to prove; but this essay not being intended as a complete treatise on every branch of the business, we cannot extend this chapter farther by a description of the *boiler making machine;* and it is the less necessary, as the pa-

* A writer in the last number of the "American Journal of Science" remarks, that "nothing but a steam navy can protect itself, much less a nation, from insult," and declares it to be "preposterous and absurd for any nation to exhaust its resources upon so useless and lumbering a thing as a *sailing* ship of war."

tentees have published a descriptive circular with drawings, &c., which may be had on application, gratis. The same thing may be said of the *boiler cleaning machine*, and most other machines for which there are patents, mentioned in the course of this work.

CHAPTER V.

ON THE DEPOSITION OF SEDIMENT, AND INCRUSTATIONS OF BOILER SCALE.

231. THE practice of allowing six or seven feet of water surface per horse power, and of making the boilers rather wide and shallow, prevails in many places where the water is more than usually dirty; and the reason generally given for it is, that the sediment, by being deposited over a larger surface, is proportionally so much less in thickness, and therefore the boilers are enabled to work for a longer period without being cleaned out.

Now, plausible as this notion may appear, the parties who first conceived it, most certainly could never have personally examined the inside of a boiler after it had been at work; for the fact is, that the sediment never is, in any case, thus spread equally over the boiler bottom, but is always found accumulated in one or more heaps (principally in one heap) in some quiet corner of the boiler, or where the water happens to be the least agitated. Even Mr. Farey, in his excellent treatise on the steam-engine, recommends that the bottom surface should rather be too much than too little, and gives a similar reason to the above, adding, that it is the most effectual means of obviating or diminishing the evil of bad water. Trivial as a misconception of this kind may at first sight appear, its effects are not so, and it is not so easily removed as one might at first suppose. But as a proper understanding of this subject is of the very highest importance, in respect of its bearing upon the subject of explosions, and any neglect in attending to it being frequently productive of the most calamitous consequences, we shall, at the risk of being thought tedious, give a short explanation of the principal facts concerned.

DEPOSIT OF SEDIMENT.

232. All natural waters, with the exception perhaps of rain-water, hold various foreign matters both in solution and suspension: when in the latter state, they admit of being removed by filtration; but any system of filtration, on a scale sufficiently large to supply a moderate sized steam-engine, would be found to be very troublesome and expensive. From the tendency, however, which the sediment has to accumulate in heaps, as already stated, it is only necessary to place one or more vessels within and amongst the water of the boiler, when the *whole* of the sediment will very soon deposit itself within such vessel or vessels, provided, of course, that they are of sufficient capacity to hold it all. This is, in fact, nearly the whole of the principle of Mr. Scott's patent invention for preventing steam boilers from becoming foul *. The late Mr. Tredgold was, no doubt, well acquainted with this principle, as he recommended that a portion of the boiler should be partitioned off by a division plate, extending across the water chamber of the boiler near to the back end, and reaching nearly to the surface of the water, into which, he

* For the specification of this patent, see the "Repertory of Arts," (new series,) vol. vii. page 257, and for a description of it, the "Mechanic's Magazine," vol. x. page 234; see also a paper at page 332 of the same volume, written by George Peel, Esq., of Manchester, to whom the author is under considerable obligations for various information connected with this work.

said, the sediment would deposit itself; but it does not appear that his plan was ever put into practice.

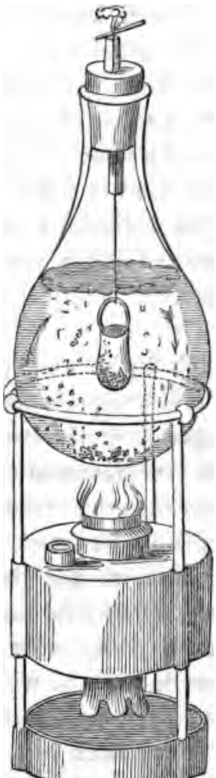
Although the principle which operates in causing sediment to accumulate in certain quiet places along the banks of rivers, or behind natural or artificial obstructions in the current, as well as in accumulating sand banks through the counteraction of opposing currents in the open sea, is sufficiently evident, and is well known as a most interesting branch of study in civil engineering; yet because the fact is well known, and seen daily, no new questions are asked about it. However, in the case of a steam-engine boiler the operation of this principle is not so apparent, and its application is still further involved in difficulty, when we discover that the tendency of the sediment to accumulate in heaps is increased in proportion as the circulation of the water is prevented or interrupted.

233. To illustrate this by an example, take a small open topped boiler, with a division plate fixed water tight across it, forming a mud receptacle at the back end of the boiler, according to the plan recommended by Tredgold, as mentioned above. Then, on the application of the lamp furnace, the particles may be plainly observed, even before the water comes fully to boil, to rise up and jump over the division plate into the receptacle allotted for them. It is, of course, to be understood, that the lamp must be placed at the contrary end of the boiler to that at which the receptacle is fixed; for by changing the position of the lamp, the sand may be all made to return back into the other part of the boiler again.

234. This experiment may be varied in the following manner, which is more illustrative of the subject in hand, and admits of being repeated easily on a small scale, and with an apparatus of the cheapest possible kind. The sketch,

fig. 20, is meant to represent a common Florence flask, containing water kept gently boiling by means of the argand lamp below it. Suspended in the flask by a piece of wire is a small glass bucket for a sediment vessel. Now with an apparatus like this, and by using any kind of soil, sand, or other sediment, it is very easy to prove the bare fact that

Fig. 20.



such sediment will all rise from the bottom and be collected into the sediment vessel or collector; but this is done so rapidly, generally in less than half a minute after the commencement of ebullition, that in order that the process may be more distinctly perceptible, a more careful arrangement is necessary. This is effected by having the flask stopped with a good cork, through which is inserted a tube of very fine bore; and through this tube the wire is passed which suspends the glass bucket or collector. Thus by impeding the issuing current of steam we can keep up a very slight pressure, and thereby in some degree assimilate the flask to the condition of a steam-engine boiler. Instead of using water discoloured with any kind of dirt, take a few minute fragments of any insoluble substance, whose specific gravity is not much greater than that of water. Then, by carefully trimming the lamp, and placing the apparatus between the observer and the light, and in a place free from any draught of air, the operation may be easily watched. When this is done with sufficient care and attention, we may observe the steam first begin to form under the small fragments at the bottom of the flask, which are frequently lifted up a little way from the bottom, when the minute bubbles of steam which support them successively collapse as they rise into, or are met by, the circulation of a colder portion of fluid, and the fragment instantly drops: this simmering process goes on for a few minutes, the particles of sediment rising higher and higher, until the water has nearly arrived at a uniform heat, or approaching to the point of ebullition, and which is always found to be at one or two degrees lower temperature than when distilled water is used free from sediment. Now at this particular period of the experiment, if we adjust the lamp with care, we may distinctly observe that the steam is generated only at those particular points of the heating surface which are touched by the small fragments or particles of the sediment used. In fact, every particle of sediment becomes a small *moveable generator*, and acts precisely on the same principle as the large or *fixed generator* described in the last chapter but one; there being no particular difference, except in dimensions, between the large fragment of brick suspended in the flask, as shewn in fig. 14, and any minute particle of (it may be) the same substance, as shown in fig. 20.

235. The careful experimenter will now be at no loss to account for the fact, that each particle of sediment rises up to the surface of the water as it were of its own accord, and deliberately deposits itself within the sediment vessel; for he actually sees the steam form underneath the angular and uneven surface of each fragment or large particle of sediment, and he also sees the fragment borne to the surface of the water by the buoyant power of the steam so formed. When the fragment has arrived at the surface, it is there of course separated from the little bubble of steam which supported it, and is projected in various directions, depending upon the circulation of the water and other circumstances; when, if it passes over the sediment vessel, where there is a portion of the fluid which is in a partially quiescent state, or in some degree sheltered from the constant upward action of the continually arising bubbles of steam, it then falls by its own gravity into the collecting vessel, and which in this manner becomes as it were a trap for the sediment.

236. Sediment vessels have been proposed, and also occasionally used, of a kind different to the above, by having an external vessel or receiver connected with the boiler by a large pipe, or other convenient opening, into which a portion of the sediment passes every time the pipe or valve is opened. This plan is particularly remarkable for its clumsiness, when contrasted with either of the other; for the receiver, or sediment vessel, being placed outside the boiler, is required to be at least as strong as the boiler itself; besides this, the pipe which connects it with the boiler bottom must necessarily pass through or very near the fire, and is consequently very soon destroyed. A plan of this method of cleaning boilers may be seen by referring to the plate of Brunton's patent boilers, in Partington's very useful work on the

Steam Engine*; also to plate 3 of the new edition of Tredgold.

237. The great merit of Mr. Scott's method is its peculiar simplicity and cheapness, for we have nothing more to do than to suspend, within the water of the boiler, a common wooden bucket, or vessel of tin, or earthenware, or any other material, or even a bag of moderately close or compact texture; and any one of these receptacles, if judiciously placed, will collect into itself the whole of the sedimentary matter from the water, and which of course may easily be withdrawn or removed at any convenient opportunity, without its ever coming into contact with the bottom or sides of the boiler.

238. There is a singular circumstance connected with this self-cleansing process: place two sediment vessels in in a boiler, submerged to the same depth, and close to each other, let them be of equal capacity but of different shapes; one of them being wide at the top, or say in the form of a bason, while the other is contracted in that part, or nearly in the form of a bottle with a comparatively narrow neck; then if the boiler be opened after a certain portion of time, it will be found on examination that *the narrow-necked vessel is nearly, if not quite, full of sediment, whilst the wide-mouthed one has little or nothing in it.* The reason is obvious enough, for although the water never boils in either of the vessels, yet it is subject to a little more agitation in the wider mouthed one than in the other, consequently the dirt is *attracted*, if the expression may be allowed, into the quietest of the two.

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* An Historical and Descriptive Account of the Steam Engine. By C. F. Partington, of the London Institution. 2nd edition. 8vo. London, 1822.

INCRUSTATION OF DEPOSITS.

239. Although we have seen how to free a boiler from sediment and other gross matters, that are held in mechanical suspension in the water, it may be asked what means we take to get rid of the incrustation, which being generally formed from matters previously held in solution, appears to be rather a formidable difficulty. The answer is, by an application of the very same principles which have been shewn to be so efficacious in the case of the loose sediment.

Perhaps nine-tenths of the substance of all incrustations to be found in boilers, (independent of the insoluble matters already disposed of,) consist of *carbonate of lime*, having been previously held in solution by an excess of *carbonic acid*, the latter, of course, continually varying or fluctuating in its amount, according to the circumstances of the boiler, while the carbonate of lime, which is in the feed water when it enters the boiler, is regularly increasing, nearly at a uniform rate; consequently, the deposition goes on more or less rapidly at irregular intervals, always depending upon the proportions of these two substances present at any one time.

240. Now the circumstances under which a steam engine boiler is placed, necessarily include a great variation in the state of ebullition of the water, it being most violent when the demand for steam is the greatest, and at such times we may conclude, that the superabundant carbonic acid, as well as the atmospheric air, and all other gases that admit of expulsion by boiling, are present to a much smaller amount than at any other time,—of course the carbonate of lime is then deposited, and obeys the same laws as any insoluble deposit; consequently it accumulates in the sediment vessel or collector, precisely for the same reason as does the argillaceous and other sedimentary matter, as already explained. In fact, the carbonate of lime, although called a *chemical* deposit, is, at the time of its deposition, as much a *mechanical*

one, as that of any insoluble matter, and it becomes so, the instant it separates from the water in a solid state; but being an impalpable powder, it requires a collecting vessel more perfectly free from agitation than the coarser mechanical deposits. The principal difficulty is to retain it in the sediment vessel until discharged; this object, however, was partially attained by an apparatus which the author contrived and brought into use in 1829; it was made by forming the upper part of the collectors of a hopper shape, to which was attached a lower part or receiver, made perfectly water tight, —from this receiver a pipe was carried to the outside of the boiler, through which, by means of a valve, the contents of the receiver were discharged as often as necessary.

241. The object of the above contrivance, was to combine the principles of Maudslay and Field's patent of 1824, to that of Mr. Scott's of 1827, with the intention of making it useful for marine or steam-packet boilers. Now the proper use of this discharging apparatus is essential to the attainment of the object of keeping the boiler moderately free from *incrustations of carbonate of lime;* for if this deposit is allowed to remain in the receiver too long, it is liable to be in part re-dissolved by any increase in the quantity of *free carbonic acid,* only to be again re-deposited, but which, of course, may be prevented by *blowing it out frequently* along with the rest of the sediment.

That this apparatus is not yet fully adopted in steam packets, arises from the same causes which so long delayed its general use in factories. When first tried in the City of Dublin Company's packet, the *Shamrock*, its perfect efficacy was shewn—so far as can be expected of any new invention, when there has not been sufficient experience to perfect all its details. The apparatus was proved to collect the thick brine as the latter became concentrated by the evaporation of the sea water, which, while being blown out, partly crystallized, or assumed the state of a fine salt, with just as much water as was sufficient to hold it in a semifluid state, and which is essential to its discharge*. The discharge was effected by the pressure of the steam acting suddenly upon the contents of the receiver, and blowing them through a pipe fixed in the side of the vessel.

242. Notwithstanding that the above-mentioned apparatus was made so far back as five years ago, which ought to be considered a very long period in this age of improvement in steam machinery, all particulars relating to the trial, which was in every respect a successful one, were contrived to be so effectually burked by some of the superintending mechanical marines, that the principal Director of the Company † was only for the first time made aware of the fact of its having been tried at all, through the publication of the second edition of this book, eight or nine months ago! This will not seem strange to those who are acquainted with the usual policy of *successful* patentees in their mode of doing business with nearly all large companies, when informed that the cost of the apparatus in question is *under* twenty pounds, consequently there is no room left for what we have heard technically, though sometimes truly, called "plunder."

Indeed in the eyes of those whose interests are extensively concerned with the old destructive plan of managing boilers, the simplicity of this mode of keeping a boiler clean no doubt appears quite contemptible when compared with other

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* The fact of the collection of the salt and salt brine was first exhibited, on a small scale, to Dr. Clanny, of Sunderland, the well-known inventor of the blast safety lamp, in 1827; and the application of Mr. Scott's patent collectors to that purpose was first successfully tried in the boilers of the Solway steam packet, at Liverpool, in 1830.

† Charles Wye Williams, Esq., of Liverpool, inventor of the compressed peat coke and resined fuel; respecting which see a valuable paper just published in Newton's London Journal for February, 1839.

plans for effecting the same object at one hundred times the expense, leaving profit enough to retain a little regiment of puffers, &c. It is, however, but justice to add, that the above Company have now ordered some more of their vessels to be furnished with the cleaning machines. The Duchess of Kent steamer having been recently so fitted, under the surveillance of Mr. Williams himself, that gentleman took a most ingenious and effectual method of demonstrating the utility of the plan, by having the end of the discharge pipe inserted into a large cask, which was placed in the stoke-hole, and into which the contents of the collecting apparatus were discharged, instead of blowing them into the sea. The quantity of sediment thus collected in one voyage from Liverpool to Dublin and back, was found to amount to nearly two hundred weight; this was after it was allowed to subside and the water drained off; it consisted of a stiff pasty mass of carbonate of lime, and when dry had very much the appearance of common lime mortar.

This great quantity of deposit was obtained from the centre boiler alone, of three independent circular boilers, being after the rate of about three tons every ten voyages, and which was, of course, somewhat more than had ever been found to accumulate in the boilers in the same length of time, owing to its containing that portion which would have passed off by blowing off the boiler for the purpose of changing the water in the usual way, a practice which was continued, although perfectly unnecessary when the cleaning apparatus is used, the latter answering the purpose of the usual blow-off cocks in this respect, but with infinitely less trouble and greater safety.

243. Returning to the subject of land boilers, which is the more immediate object of this Essay, we must remark that in addition to the *carbonic*, there are very few hard waters that do not contain some small portion of *sulphuric acid.*

This acid is almost insensible to any ordinary test, yet the continued working of a boiler for a few weeks causes its constant and gradual augmentation, or concentration of its strength, and if there be any lime present, *sulphate of lime* is at last formed, which seems to attach itself to the iron with such tenacity that it almost defies the hammer and chisel to remove it.

244. Various chemical remedies have been tried to prevent the incrustation of this troublesome deposit—in particular, animal substances of all kinds seem to have a good effect; and in this district potatoes are frequently put into the boilers for the same purpose, although they are not quite so effectual as animal matters.

The exact mode in which the potatoes act in preventing the adhesion of sulphate of lime, is yet a question among chemists; some are inclined to think that they do not act *chemically*, but *mechanically*. Such is the opinion expressed in a paper published several years ago in the Journal of the Royal Institution, entitled Practical and Philosophical Remarks on Natural Waters, by William West, Esq., from which the following is an extract:—"The adhesion of the earthy matter to the iron is lessened, and the interval between the cleanings consequently protracted, by the use of potatoes; the pulp of which, by enveloping the crystals, lessens their tendency to adhere, and preserves them for a while suspended in the water of the boiler."

245. It was the consideration of the possibility of keeping the sulphate of lime mechanically suspended in the water of the boiler, as stated in the above extract, which first suggested the idea of also using the sediment vessels, for the purpose of catching this chemical deposit along with the argillaceous and other heavier kinds of sediment, in the manner already described; for whatever might be the best method

of preventing the sulphate of lime from adhering, it was plain that some apparatus for collecting it and getting it out was just as necessary in one case as another.

A modification of Mr. Scott's patent collectors, with the addition of an agitator, which is worked by a small shaft or spindle passing through a stuffing box to the outside of the boiler, answers the purpose very effectually, as it admits of the use of potatoes, or any other treatment to which the boiler may be subjected for the sulphate of lime, without the liability of the apparatus becoming clogged up.

The openings into the collecting vessels of this apparatus, or self-cleansing machine, are made sufficiently small to enable it to catch *nearly all the carbonate of lime*, while it also catches the *whole* of the loose sediment, and which is discharged from time to time, without any interruption to the working of either the boiler or engine.

246. The above apparatus, in its present improved state, is called a *machine*, although it is not exactly a machine in the ordinary acceptation of the word, on account of the extreme simplicity of its construction, there being neither wheel nor pinion about it, nor indeed any of the other mechanical powers, unless the lever of the handle may be so called, which puts the discharging apparatus in action. Moreover, unlike all other machines, its most important functions are performed while standing still. It is never put into action but two or three times in the course of a day, for discharging or "blowing out," and that for less than half a minute each time, according to the quantity of sediment which it has collected; consequently, it is not very liable to wear out, besides rendering its first cost comparatively small *.

* The Author of this work, by an arrangement with the Patentee, made and fixed up several hundred of these boiler cleansing machines; the boilers to which they are attached not having required any other

A good deal has been said and written about the stupendous powers of the steam engine, and our northern neighbours, in particular, have been exceedingly magniloquent in their praises of the mechanical wonder. Some years ago, one of the Edinburgh Reviewers, amongst other nonsense, stated that the steam engine could "*embroider muslin*," and "*lift a ship of war like a bauble in the air;*" which looks very well in print, but, like some of the stories of Macpherson's fabled heroes, loses all its charms when we know that it is not true. It must, however, be acknowledged, with the Frenchman Belidor, that it "is the most wonderful of all machines, and that nothing of the work of man approaches so near to animal life." For as this author also goes on to state, the steam engine "feeds itself, evacuates such portions of its food as are useless, and draws from its own labours all which is necessary for its own subsistence." This description, although rather of an imaginative caste, considering that it was written about a century ago, may not be much amiss, if, instead of the engine, it be applied to the Boulton and Watt boiler, as improved within the last twenty years; for of the boiler it may now be stated, with some degree of truth, that it performs for itself the whole of the above actions, along with some others that have a closer resemblance to those in the animal economy, denominated involuntary,—amongst which we may mention, the half chemical, half mechanical, processes of digestion and secretion, as well as *the separation of excrementitious matters*, which in physiology is considered to be a peculiar *vital* function.

247. When boilers are cleaned out in the usual way, it is always observed that the diminution in the quantity of fuel

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mode of cleaning out for some years. There are nearly 200 of these machines now in use in Manchester alone.

required for getting up the steam is very great (except for the first morning) for some days after; yet before the end of the first week a sensible increase takes place, besides a gradually increasing expenditure during the day, independent of that required for getting up the steam each morning; but the most marked increase is on each successive *Monday morning*, when, owing to the boiler having been off work during the Sunday, a portion of the sediment which has been thrown down, frequently assumes the appearance of baked earth or clay. This kind of incrustation usually has a semi-vitrified, or half burnt appearance, on the side which has been next to the iron of the boiler bottom, and is generally called boiler-scale, as distinguishing it from the incrustations of calcareous or other mineral salts, which have been already noticed; for the former generally chips off in small *scales*, which are found loose in the boiler. The crystallizations of carbonate and sulphate of lime never do so, unless combined in some considerable degree with the former, but, on the contrary, require the hammer and chisel to remove them, as before stated. Now we ordinarily find these two substances, the argillaceous and calcareous incrustations, to be combined in various proportions with siliceous matters, forming stalagmitical masses of partially crystallized boiler scale, and thus producing a kind of triplicate salt, that has as yet escaped the attention of those chemists who are more distinguished for inventing new names for old substances than for discovering new or useful facts.

248. Some of those incrustations are harder than marble, and when polished are very beautiful; many of them have a stratified appearance, which indicates exactly the number of weeks that a boiler has been at work, and on examination with a microscope, minute strata may be observed, distinguishing the deposit of each day. The upper surface of some kinds of boiler scale is also exceedingly curious, and

takes almost the appearance of a kind of vegetable formation,
—there are peculiar varieties of this kind of boiler scale, belonging to different boilers and different kinds of water, and which are well known.

249. There are deposits occasionally to be found in boilers which, to some, may perhaps appear in a rather questionable shape. They are detached substances, being nearly perfectly *round balls*, and are found in considerable numbers in cylindrical boilers. They are generally of various sizes, in the same boiler, from that of a pea to a large-sized marble, but are sometimes met with from one to two inches in diameter—although there is always a determinate size beyond which they do not appear to grow, in the same boiler, and should the boiler go a longer time than usual without being cleaned, they merely increase in number. It is remarkable that these boiler balls exhibit, in their conformation, some degree of similarity to the calculi which are found in the human bladder, as described by medical writers: they usually admit of separation into a succession of concentric layers, like the coats of an onion, although sometimes ending, in the larger sorts, in a central hollow nucleus, containing water. The largest that we ever found were two inches in diameter, and were repeatedly obtained from the cylindrical boiler described in Art. 12. The water used in this boiler was from the water works, generally known in Manchester as the "stone-pipe water." The composition of the balls is a mixture of clay and vegetable mould, with a little of some glutinous substance. This boiler produced the balls at the rate of about half a bushel every two or three months.

250. It may be mentioned that the introduction of the cleansing machine into the above boiler, put an end to its ball-creative faculty, as it likewise did in all other similar

cases, except in one; and in this instance they were collected and blown out by the machine while very small. These last are not so round as the former; they are partially hollow, and have a whitish appearance, being principally composed of carbonate of lime, and clay.

251. There is another species of detached mineral substances produced in boilers, but of much rarer occurrence than the former, as we have not yet met with any but from one boiler, in which they had been produced at the rate of half a bushel per month for about a year. These were hollow, perfectly white, and in size, shape, and appearance, very much like birds' eggs; they were very light and easily broken, and then exhibited a delicate kind of cellular formation, not unlike some of the more fragile sorts of shells—they were accordingly called shells by the person who first informed us respecting them. Most of them were found broken in the boiler, or broke with handling; and we always found a drop of very pure water, with a few grains of loose sand, in each of the cells. They were submitted to the examination of Dr. Dalton, who pronounced them to be nearly pure carbonate of lime, and the water from the spring which supplied the boiler contained the same substance.

252. It is a matter of some moment to those who filter the water, previous to allowing it to go into their boilers, to know that the incrustation, although less in quantity, is then always the hardest and most difficult to remove. It is then also more difficult to prevent the partial deposition of the sulphate or carbonate of lime by a free use of the cleansing machine; consequently, some parties who had been at the expense of filtering water for the use of their boilers, have discontinued doing so, and with considerable advantage.

253. When the boiler scale is once formed, it is of some importance to be able to remove it with the least detriment

to the boiler. The best way of doing this is, to make a small sharp fire of wood under the boiler for a few minutes, when the latter has no water in it; and then the great expansion of the iron will cause the boiler bottom to throw off the incrustation in very large cakes or scales. We have obtained large pieces of scale in this way, an inch thick, and several square feet in area.

Now the necessity of attending to the effects of those accumulations of fur or scale, on economical considerations, is very evident, but there is a much more important point of view in which we ought to examine those effects, and that is in connection with the enquiry as to the causes of some hitherto unaccounted for explosions, of which we shall treat in the next chapter. The importance very properly attached to this inquiry at the present time, and the interest which every right minded person must feel in advancing even the least step towards insuring perfect safety in this respect to our numerous passengers by steam vessels, renders it incumbent on us to leave no new facts unstated that bear particularly on this branch of the subject.

PREVENTIVES OF INCRUSTATION.

254. We have already shewn that scale arising from argillaceous deposits, may be entirely prevented by the cleaning machine as well as when those deposits are mixed to a considerable extent with calcareous substances. Also when the scale is a nearly pure carbonate of lime, or with very little admixture of argillaceous, siliceous, or other adventitious matters; it is by this means easily prevented accumulating to any injurious thickness, and without the addition of using any chemical means whatever.

When, however, any considerable portion of the incrustation is composed of the sulphate of lime, some little trouble and difficulty is experienced in preventing its slow but gradual and certain increase.

255. As has been previously stated, (Art. 244,) crushed potatoes are usually put into the boilers as a preventive of this kind of scale, and we have ascertained that if frequently renewed they are very effectual for this purpose, but they do not admit of being used in conjunction with the cleaning machine unless put in daily, as the latter invariably collects them and blows them out along with the other matters.

With a view to prevent or diminish this trouble, we several years ago adopted the plan of having a very large quantity of *whole* potatoes placed in wire cages, or in vessels perforated with numerous holes, and suspended in the water chamber*. This plan admits of a free use of the machine, and keeps a boiler moderately free from any injurious incrustation.

256. Operative engineers have been long conversant with the fact that animal as well as vegetable substances are generally efficacious in preventing fur and scale accumulating, and which was no doubt originally inferred from observing that the ordinary culinary boilers used for boiling meat and vegetables never fur up, while the tea kettle which is used for boiling spring water alone uniformly does so.

In accordance with the above remark, animal matters of all kinds have been used indiscriminately as well as most vegetable substances; amongst the former we have always found that cows' feet or any other portion of the animal capable of being converted into jelly, to be preferable to almost

* It is a remarkable fact, and not generally known, that potatoes may be boiled in a steam engine boiler in this way for a month together, and when examined at the end of that period, are found perfectly whole, and in appearance exactly the same as when first put in. After exposure to the air, however, they soon become shrivelled, the extractive matter being entirely gone, leaving nothing but a light fibrous substance besides the external skin.

any thing else. Indeed the opinion expressed by Mr. West before referred to (Art. 244) respecting the mode in which the pulp of the potatoes acts in preventing the adhesion of the sulphate of lime, induced us to place great reliance on any substance capable of conversion into either animal or vegetable jelly, and extensive experience has since confirmed this opinion.

257. Although potatoes are generally used in Lancashire for this purpose, they are perhaps inferior in effect to most animal substances, but they are cheaper, and as they are more cleanly, they are therefore more suitable for those boilers that are used to generate steam for various processes where grease of any kind would be inadmissible, as in printing, bleaching, and paper-making works.

Those who use their steam solely for their engines, are commonly in the habit of putting into their boilers any kind of dirty grease or tallow, such as the scrapings from the ends of shafts and other portions of the mill-work, and we have usually observed this to produce a better effect than when clean tallow alone was used.

258. Some people brush over the insides of their boilers every two or three weeks with melted tallow; we have also tried successively coatings of blood, gas-tar, various kinds of paint and size, and found the best of them to be merely palliatives for a very short time. And Mr. Dinnen informs us that it is now the practice in the government steamers (by orders from the Admiralty) to brush over the internal parts of the boilers with a mixture of blacklead and tallow *,

* A report to the Admiralty on this mixture by Mr. Johns, the chief engineer of the "*Spitfire,*" may be seen in the Civil Engineers' Journal, page 191, for May, 1839.

(the celebrated *anti-attrition composition*,) but its superiority to other things of the kind seems at best but problematical.

The use of tallow generally is, we think, objectionable on many accounts, some of which we have before stated. The principal one is that it increases the liability of the engines to prime, although we have been informed that it is a common practice with some engineers of steam packets on the Thames to throw a lump of tallow into their boilers *with a view to prevent priming!* This is not a little singular, if true, for it would thus appear that what is accounted to be the principal cause of this evil on the *Mersey*, is used as a preventive on the *Thames*. The fact, if it be one, probably deserves a more attentive examination than we can here go into; but it may be suggested, that the water in some situations may possibly hold a sufficient quantity of alkaline ingredients to combine with a portion of the tallow, and form soap; by this means a foaming up of the surface of the water would be created, and consequent liability to prime. On the contrary, in other situations, from the absence of alkaline matters, the grease may possibly have rather a beneficial effect, by partially preventing the violent breaking or agitation of the surface of the water, in a somewhat similar manner to the effects said to be produced by oil, in stilling waves at sea.

259. Since the publication of the last edition of this work, the above remarks on the incrustation of boilers have received a certain degree of corroboration in the specification of a patent granted to Mr. A. W. Johnson, on the 30th June, 1838, "for an invention of certain improvements for preventing the incrustation of steam boilers," and it is stated to be a communication from a foreigner residing abroad, which circumstance probably accounts for many things being claimed in it that are not new. The following extract from the specification of this patent is given merely

to shew that the theory therein contained corresponds exactly with that of Mr. West, which was published nine or ten years ago.

The invention is described as consisting, "firstly, in the use and application of vegetable matter or extracts, which being thrown into or infused in the water with which the boiler, steam generator, or other vessel is supplied, by a chemical action, lays hold of, and envelopes in a thin coat or film, all the earthy, calcareous, and metallic or other particles which are held in suspension, or may be produced or developed in such water by the action of heat. The adhesion or affinity of such particles to each other is thus destroyed or intercepted, and by that means their adhesion to the sides and bottom of the boiler or other vessel is effectually prevented. All kinds of vegetable matter or extract, either in a solid, pulpy, or liquid state, may be used indiscriminately; but I prefer the extract of such vegetable substances as contain and give out the greatest quantity of colouring matter, such for instance as logwood, and other dyewoods, bark, or tan, and grasses of every description, whether in a fresh, dry, or decayed state. I also particularly recommend the use of decayed or putrified vegetable matter in general, such as turf, peat, manure, leaves, and other substances of that kind. In short, I declare the essential principle of this part of the invention to be the impregnating with vegetable matter or extract, the water used for the purposes above alluded to, whereby the tendency of the earthy, alkaline, metallic, and other particles held in suspension or solution in the water to adhere to each other is counteracted, and the incrustation of the boiler or other vessel prevented in the way above stated."

In addition to the above, this patentee, in evident ignorance of the boiler cleaning machine, also specifies a modification of Mr. Scott's sediment collectors communicating by means of a pipe with an external receiver, placed below the boiler, on the principle described in Article 236, but more particularly liable to the objections there stated.

260. In referring to other patent inventions for freeing boilers from deposit, we may conclude this subject by mentioning that of Mr. William Taylor, of Wednesbury, dated January 19th, 1831. This gentleman does not use internal collectors, as in Mr. Scott's invention, nor an external receiver, as in that of Mr. Brunton's; neither does he combine these two plans, as in the above described patent of Mr. Johnson; but he forms the lower part of the boiler into one or more dish-like receptacles, extending below the fire for the purpose of collecting the sediment, and to which valves are attached for blowing out frequently. Now it hardly needs to be stated that the principle of this plan is precisely that on which marine boilers have always been formed; but the idea of blowing off any considerable quantity of deposit from the *bottom* of a boiler while the latter is at work is perfectly erroneous; and no portion whatever of that which would be likely to settle upon the *top of the flues* and produce scale ever was, or can possibly be so blown off unless the whole of the water in the boiler is blown out altogether. The fine impalpable precipitate which creates incrustation can only be collected effectually at or near the surface of the water. Any substances heavy enough to be deposited on the bottom of a marine boiler while the latter is at work, may as well lay there quietly to the end of the voyage; for they can do no injury until they reach up to the bottom of the flues.

CHAPTER VI.

ON EXPLOSIONS.

261. Explosions of steam boilers have occurred so frequently of late years, and have been attended with such disastrous consequences, particularly when they have happened in steam packets, that the subject calls loudly for legislative interference. In America, where the explosions of steam packet boilers have been more frequent, from the general use of high pressure engines, some legislative restrictions have been recently adopted, founded upon a set of very ably conducted experiments, peculiarly adapted to the practice in that country. A few points, however, remain open to investigation; and as the subject must be one of intense interest to all those who, with a laudable anxiety for improvement, combine a proper regard for the welfare of their fellow-creatures, we shall examine as much of it as regards the safety of the ordinary low pressure boiler, as generally used, and which comes more particularly within the scope of this Essay.

262. It is frequently observed that a boiler of about thirty horse power will require from a ton to a ton and a half of coal extra, during the first day after it is cleaned out. This arises from the practice of cleaning out the boilers, as well as the flues, by means of human beings, instead of mechanical contrivances, although the latter are easily available for both

purposes. The means of effecting the former have been already described, and have been adopted to a considerable extent; but we have not such sanguine expectations that similar means of cleaning out the flues will be so readily adopted, the pecuniary advantage resulting therefrom not being so apparent as in the other case.

263. The ordinary practice in Manchester is to clean out the boilers once a month, and to clean out the flues at the same time; preparatory to which the boilers mostly require filling once or twice with cold water, to cool them: consequently, in getting up the steam the next morning, there is not only all the extra fuel required for heating the comparatively cold water, but quite as much more is required to bring up the mass of brick-work, and all the adjacent parts, to their former temperature. It is of little or no avail that there may be a spare boiler kept, for the cooling of it is still necessary, either by standing a week, or in one way or other, and of course the loss is the same.

264. It generally happens, that the spare boiler, if there be one, stands immediately adjoining those that are constantly at work, and the heat from the adjacent boilers and brick-work renders it quite impossible to clean out the flues without an amount of individual suffering which few people have any idea of. The ordinary climbing boys are not generally employed to sweep the flues of a steam-engine boiler in a factory; a strong man usually is required for the purpose. Quite a different sort of manual process is necessary than that used for sweeping a common house chimney; indeed the latter must be, comparatively, a pleasant occupation. In the former case the man has to *worm* himself through the flues, in a horizontal position, pushing before him the contents of the flue, or "flue dust" as it is called; which is not soot, but a heavy kind of deposit, consisting of very fine

ashes, being the burnt earthy particles of the fuel, which are fine enough to be carried forward with the draught. The most expert hands at this kind of work are generally natives of the sister isle, who are ever ready, for the smallest pittance, to undertake this drudgery, and with whose labour, as to value (at least as to price) it is in vain to attempt competition with machinery. It is from the above mentioned class of men that the stokers or firemen for the steam-engines in Manchester and Liverpool are generally obtained; and certainly there are none so capable of being made good firemen as intelligent Irish labourers, especially if they have been previously good spademen.

The foregoing may seem to bear only very remotely on the question of explosions, but it is rendered necessary in order the better to elucidate a view of the subject, according to which it is believed we may account for the great majority of the explosions which have occurred in factories and other large works.

265. It is a fact very well known, that many of the explosions of steam boilers, which have occurred of late years in the factories in this district, have taken place on Monday mornings, a little before six o'clock, and it is generally believed that the whole of those have done so, whose causes have not been hitherto clearly ascertained. Now if we take into consideration that the firemen have generally the charge of cleaning out the boilers and flues, and that along with this they are commonly charged not to be seen doing their work on a Sunday; then, bearing in mind what we have stated, of the difficult nature of the operation, rendered still more difficult when it is obliged to be done on a week day, when the fires are burning in the adjoining furnaces, perhaps one on each side, merely separated by a thin brick wall, adding to this the necessity of keeping the damper of the spare boiler closed, otherwise the fires under the other boilers do

not burn properly,—this work has, on all these accounts, generally become a night job, consequently there can be little superintendence of either masters or managers, and therefore it is not to be wondered at if the boilers and flues very frequently go without any cleaning at all.

266. In illustration of the usual routine of the fireman's business, we may state that it sometimes goes on this way:—Suppose the getting up of the steam to require three or four hundred-weight of coal extra on the Monday morning of the second week after the boiler and flues have been cleaned; the Monday morning after that it will require five or six hundred-weight, and thus it will go on requiring a few hundred-weight more at the commencement of each week than in the preceding one, until the boiler goes several weeks without being let off—the consumption of fuel going on all the while in an increasing ratio, along with an increased difficulty of raising the steam, until, at last, the poor stoker sometimes finds that he cannot raise the steam at all. This is, of course, a consummation that rarely takes place in regular factories, where there are seldom fewer than two or three boilers, and therefore the steam which cannot be obtained from one boiler must be had from another; but at collieries, and in many country places, where there may be only one boiler to an engine, it occasionally occurs. Now, the consequence in the majority of those cases, is generally of little account, excepting on the score of economy, for the boiler has only to be let off and re-filled, and all is right again; but it is altogether very different at a factory, where there may be a good chimney and a strong draught, and also several hundred workpeople depending upon the engine starting at the proper time—in such a case, as it is sometimes significantly expressed by the enginemen, there must be steam or else a *blow-up* of one kind or other.

267. Most people are aware of the rage for building very large factory chimneys, during the last few years, and as they are usually built much larger at first than the wants of the factory require, there is always a surplus draught, which, by setting the main damper wide open, can be taken advantage of to any extent, and in many cases to cause an intensity of heat almost equal to that in a blast furnace. Where this surplus draught is easily available, the fireman has little to do but open his dampers, and the steam is got up in one half the time that it required formerly.

268. Whether the boiler is dirty, or has too much water in it, one consequence is the same, under ordinary circumstances, namely, a greater length of time is required for getting up the steam, and this necessarily requires the earlier attendance of the fireman. Now the fireman is not generally summoned at a certain hour like the regular mill hands, and if he can only contrive to get up the steam in sufficient time for the engine starting at the appointed minute, there is seldom any fault found; therefore any expedient which will enable him to prolong the period of his commencing work is not likely to be neglected, and such an expedient he has wherever there is a good draught.

269. It unfortunately happens that, in this matter, the apparent interests of the manufacturer and the real interests of humanity do not agree; for it has been incontestibly proved, that a strong draught is extremely favourable for saving fuel, as may be judged from the fact, that the time for getting up the steam has been in some instances reduced from upwards of an hour, to twenty or twenty-five minutes, and although the saving of coal has not been in any thing like that proportion, yet it has been very considerable.

270. Under similar circumstances to those just mentioned, there can be no doubt that a portion of the boiler bottom occasionally becomes nearly red hot, although this condition appears extremely inconsistent with the supposition that it is at the same time covered with water; yet we have been compelled to adopt this conclusion, from having had ocular demonstration of its possibility, as well as other reasons. We had frequently heard the fact stated by intelligent enginemen, and had more than once been called to witness it, although even then inclined to consider it a mistake, owing to the difficulty of ascertaining it clearly; for a slight approach to the incandescent state must be nearly invisible, owing to the strong glare of light from the furnace directly beneath, while any degree of heat much higher would be sure to weaken the iron so much as to cause the boiler bottom to give way.

In one instance, however, the rivet heads appeared to be approaching to a redness, and we immediately took care to ascertain that sufficient water was in the boiler. On returning to the furnace, we observed a circular space, of six or eight inches in diameter, in one of the plates over the middle of the fire, "drawn down" into a spherical segment, or swelling, of about two inches in depth, something similar in appearance to those formed on a smaller scale in glass blowing, but its further protrusion had evidently been checked by the sudden opening of the fire-door, and which no doubt prevented any serious consequence at the time. The boiler was a cylinder, of nearly six feet in diameter, and the pressure was about nine or ten pounds to the square inch. The occurrence took place just at the moment of the steam being sufficient to blow away at the safety valve, and a few minutes before the engine started. For a few days afterwards, this segmental protuberance was observed to increase gradually to a hemispherical shape, of three or four inches in depth, when it burst without doing any further damage than putting out the fire.

271. It is well known to engineers, that a similar bulging out of a portion of the bottoms of cylindrical boilers, when the fire-grate is placed too near, is a very common occurrence, and we have known boilers to work for several weeks, and even months, without bursting, after those swellings had been first formed. A precisely similar swelling to that above mentioned, took place a short time before, with a boiler of the same kind, at the same works. The chimney at these works was of an immense size, consequently the draught was extremely strong, and it was the boast of the engineer that he could, when he liked, have the steam up in a quarter of an hour,—it ought to be added, that it was also the boast of his master that he could burn the worst possible kind of coal.

272. The probability of boiler bottoms sometimes approaching a red heat, receives a corroborative proof on examination of the iron plates, in many cases, where the boilers have bulged out in the manner we have been describing, and which exhibit an appearance, well known to boiler-makers by a peculiar colour in the iron surrounding the part which has been red hot.

Whenever a boiler bottom is seen in this state, of course the only method of avoiding danger is to slack the fire immediately, by opening the fire-doors. But it frequently happens that the fireman thinks the boiler is empty, and, if he has an opportunity, he immediately lets into it a quantity of water, when the consequence uniformly is, that the boiler bursts instantly.

273. From what we have stated above as the common practice in the factory districts, we may conclude that the principal cause of boilers becoming unduly heated is undoubtedly, in a majority of cases, owing to the interposition of indurated, or encrusted earthy matter, between the heated

iron and the water, and the manner in which those circumstances operate in producing an explosion appears to be as follows: we have before shewn, (Art. 253,) that an internal coating of boiler scale is liable to crack and separate into large pieces, which are thrown off from the boiler bottom with a certain degree of violence, at some particular degree of temperature, depending upon the thickness of the scale and the kind of substance of which it is formed. This may account for some of those detonations, or reports, said to be heard immediately previous to explosions. It may be noted here, that the scale, when very thick, is always found to come off much easier, and is consequently detached by a lower temperature, than when it consists of merely a thin coating of carbonate or sulphate of lime; in the latter case it requires a much higher temperature, and only comes off in small patches of a few inches in diameter.

274. We may easily suppose, that by unduly heating the boiler, a large portion of scale may be suddenly detached, uncovering one or two plates, at a temperature something exceeding the *maximum evaporating point*, which is well known to be considerably under the lowest red heat of iron (by the American experiments it is at about 400° Fah.). Then, the first effect produced will evidently be a certain amount of repulsion between the over-heated iron and the water, which may continue for several seconds, and perhaps for a few minutes: this may account for the sudden *decrease* in the supply of steam, which has frequently been observed for a few moments just before the explosion of a boiler has taken place.

The next effect must arise from a gradual diminution of temperature, during the same short space of time, in that part of the over-heated iron which is exposed to the water,—creating a contraction of the metal, increasing rapidly as the temperature approaches the evaporating point, and causing a corresponding strain upon the rivets in the boiler bottom. The direction of this strain may generally be traced on examining the bottom plates of any old boiler; it is always found to radiate in lines proceeding from that plate or part of the boiler bottom which has been most acted on by the fire, and is usually indicated by short cracks or rents between the rivet holes and the edges of the plates.

The next and concluding step, in case of the materials not being able to withstand the strain superinduced by the contracting metal, must be the sudden giving way of some bad seam of rivets, which the most nearly coincides with what would otherwise be the true line of fracture, and which may possibly be at some considerable distance from the plate which is the most heated; thereby giving the effect of a great leverage to the pressure acting upon all that portion of the boiler bottom included within the actual line of fracture. Now the consequence is, not perhaps that this portion is blown out, as would most probably be the case with a cast iron boiler, but it will be bent or doubled back, the line of flexure running across the hottest or weakest part of the iron. A rupture being thus effected, an explosion is inevitable, if the hole made by it be sufficiently large.

ON THE FORCE OF EXPLOSIONS.

275. From the premises we have laid down, it may fairly be concluded, that the pressure of the steam, suddenly generated at the moment of explosion, will bear some near proportion to the area of the hole or aperture, and as the actual pressure exerted the instant after the aperture is formed, must be equal to the previous pressure drawn into, or multiplied by, that area, we may assume the square of the area, or fourth power of the diameter of the aperture, as representing a good approximation to the proportional force exerted—the reaction of this force propelling the boiler in a direction opposite to the aperture.

Hence, we have a reason why the bursting of a comparatively small hole in a boiler bottom produces such a very feeble effect, as compared to one of six or eight times its diameter. For if the force of explosion in any given case be called 1, then the force in any other case, producing an aperture of double the diameter of the former (other circumstances being the same) will be represented by $2^4 = 16$; if of

3 times the diameter, it will be	$3^4 = 81$
4 times	$4^4 = 256$
6 times	$6^4 = 1296$
8 times	$8^4 = 4096$

276. Some persons who have paid a good deal of attention to the circumstances connected with explosions, have doubted the possibility of steam being generated in sufficient quantity so suddenly as my explanation would seem to require: this, of course, is a matter which can only be proved by direct experiment; and such an experiment is yet a desideratum in this country. At present we have only one of the American experiments which throws any light upon this part of the subject; the repeating of this experiment on a large scale is highly desirable, although it would be attended with some danger and not a little expense. In the one alluded to, water was purposely injected into the boiler when the bottom was *red hot*, by which means the steam was raised from one up to *twelve* atmospheres (180 lbs. per square inch) *in one minute*, when the boiler exploded with violence. The American report states that in the violence of the effect, the experiment was not carried so far as it might have been, from not throwing in a sufficient quantity of water; consequently, the metal was not *cooled down to the "point of maximum vaporisation"* when the explosion took place, otherwise the pressure, as indicated by the thermometer the moment before the ex-

plosion, might have reached about 40 atmospheres in the same time.

277. The above mentioned experiment supplies an illustration of the general inutility of safety valves in case of sudden explosion. The safety valve is, in fact, a perfectly useless appendage to a low pressure boiler provided with the ordinary feed pipe in common use in factories; more especially when the buoy rod is made to pass through an open pipe of the same height as the feed cistern, instead of working through a stuffing box. This well known feeding apparatus is an infallible preventive against the steam getting *(gradually)* too high; as well as against the water getting too low; the latter being by far the most dangerous predicament of the two, and a frequent cause of explosion.

278. When a boiler bottom becomes very highly heated through the water getting too low, and a quantity of water is suddenly let in, the consequences are similar to those we have already described: for the internal coating of scale being suddenly contracted by the admission of the cold water, it is detached in the same manner as by the expansion of the iron, and the same effects are produced, although perhaps more speedily, as the water admitted will reduce the temperature of the exposed part of the boiler bottom more rapidly to the maximum evaporating point.

279. It may be asked, if our theory of steam boiler explosions be correct, how it is that we have not many more of them, as the causes to which they are ascribed may seem to be of almost every-day occurrence? The answer is, that the *bursting of boilers* is also a matter of every-day occurrence, to an amount which the public generally are altogether ignorant of. To be sure these burstings are not generally called *explosions*, although in reality they are so, being different

only in degree. It would not be difficult to prove that two or three of these minor explosions occur in Manchester every week; but when no fatal consequences ensue, and no particular damage is done to any adjoining property, of course the circumstance never gets into the newspapers, and no public notice is taken of it.

Usually, the affair has quite another name when it occurs with a wagon boiler; it is then said that the "boiler bottom has come down;" in other words, the concave bottom is forced down into a convex form, and sometimes the sides are in like manner forced outwards, about the middle of the length of the boiler. The consequence in the least violent of these cases is, that the boiler is lifted up a few inches from its seating by the bottom striking upon the top of the fire bridge. We also usually find every seam of rivets violently strained, so that the water runs through the boiler bottom like a riddle, although there is seldom a hole of more than a few inches in area.

280. The above remarks of course have reference principally to those cases where the metal of the boiler becomes unduly heated, either in consequence of the water getting too low, or from the interposition of incrusted deposits, as described in the preceding Articles (239, &c.). There are, however, other concurring causes that frequently modify the result; such, for instance, as when, instead of the bottom or sides of the boiler, it is the top of the inside flue that becomes unduly heated. And this is an extremely likely cause of explosion, when the furnace is contained within the flue, as in the Cornish boiler and some others.

281. There is a very erroneous, although prevailing opinion, that the Cornish or Trevithick boiler, with the fire inside the tube, is safer than any other kind, which opinion cannot be too soon dispelled. For it is an admitted fact by

all who have considered the subject, and however they may differ as to the precise theory of its action, that the water getting too low is a frequent cause of explosion; and if so, it must be evident that this cause must operate much more frequently to produce such an effect, when, as in the Cornish boiler, the depth of the water over the hottest part of the heating surface is only a few inches, than when the depth is as many feet as in the wagon boiler.

282. The force of the steam and water escaping during an explosion of a Cornish boiler is, however, immensely increased, by reason of its being generally all expended in one direction, that is, through the fire place in the mouth of the tube. The latter being thus converted into a sort of cannon or mortar, from which the grate bars, fire bricks, and other materials are projected with destructive effect, on every thing within their range.

It is also not improbable that the steam, as it rushes out, is reinforced by contact with the heated fuel in the furnace.

283. There are, besides the above, some other circumstances that have been observed in the bursting of a boiler of this kind, which shew that the explosion bears considerable analogy to the discharge of an immense piece of ordnance. Such, for instance, is the sound or report produced by the explosion, and which is not experienced in so remarkable a manner with boilers that have not an internal flue*.

It frequently happens that explosions of the Cornish boiler occur without the latter being in the least disturbed or

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* It has been observed, that when one or more flued boilers are working in connection with another which explodes, the water immediately boils out of the former into the latter, and a continuation of the effect is produced for several seconds, together with a prolonged rumbling sound, which has been described as like thunder.

removed from its place; such were the two fatal explosions on board the *Victoria* Hull steam-ship on the Thames, in March and September, 1838, the particulars of which are well known.

284. An explosion of a similar kind to those in the Victoria steamer, also took place not many months ago with a Cornish boiler at the Viaduct Foundry, at Newton, in Lancashire; but the boiler being a high-pressure one, the force of the explosion was much greater than in the former case. Several tons in weight of cast iron and other articles were removed by it, and a breach was made by them, of ten yards wide, through a strong wooden inclosure that surrounded the foundry yard. Indeed, every thing in the direction of the mouth of the tube, for 60 or 70 yards in a direct line and two or three yards wide, was swept away with terrific violence, including ten or eleven workmen, nine of whom were killed. The bricks which had composed the fire bridge within the tube were projected like shot from a gun to twice the above mentioned distance, and were the principal cause of the loss of life. The report was described as like a loud clap of thunder.

It is necessary to say that the incrustations of which we have spoken as a common cause of explosions, had nothing whatever to do either with this case, or those of the Victoria steamer, the boilers being quite new; these instances are only adduced as illustrations of the peculiar destructive violence incidental to this particular kind of boiler, owing to the steam being reinforced as it were within the tube, and then being all expended in one direction. Respecting the causes concerned in those particular explosions we shall have more to say.

ON EXPLOSIONS CAUSED BY MALFORMATION OR WEAKNESS OF SHAPE.

285. We may take the last stated case of the Viaduct foundry boiler as an illustration of this class of causes, for although not very commonly productive of explosions properly so called, they deserve the particular consideration of the users and makers of *high pressure* boilers.

The peculiar fault of this boiler and the proximate cause of its bursting was, that the tube or internal flue was oval in section, although the boiler itself was circular.

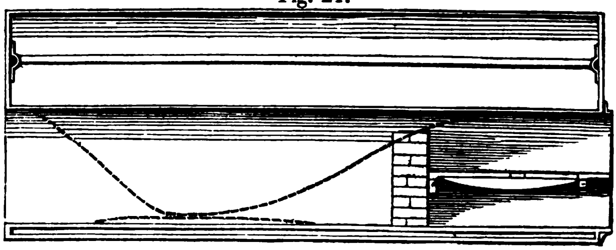
286. Now the main object in making an inside flue oval and placing it with the shortest diameter vertical, is no doubt the obtaining a greater depth of water over the flue without diminishing the heating surface; but by thus endeavouring to avoid the chance of an accident arising from a deficiency of water, we run into the contrary extreme, and risk an explosion by making the flue of a weak form.

A very slight departure from the true circular figure, not only causes a flue to be much weaker, but the pressure has a constant tendency to still farther alter the form of the curve, thereby becoming weaker with every strain, until the boiler bursts by what is called a collapse of the flue; that is, the two sides are usually crushed flat together, or nearly so, and the rupture consequently takes place in the flue itself, through which the steam and hot water are discharged in the manner we have already stated.

287. The Viaduct foundry boiler was 12 feet 6 inches long, by 4 feet 9 inches in diameter. The inside flue was 3 feet wide, by 2 feet 6 inches deep. The fire bridge was at about one third the length of the flue, and the top and bottom of the latter were crushed together at about midway

between the back end of the boiler and the bridge; the latter no doubt by acting as a momentary support to the top of the flue at the instant of the plates coming down, determined the place of the collapse as shewn in the annexed cut,

Fig. 21.



where the dotted lines shew the form which the collapsed flue assumed by the force of the explosion.

288. The above boiler was quite new, the explosion having taken place the first morning it was set to work, and within one minute after starting the engine. The plates were of $\frac{3}{8}$ inch thick, and, saving the *form* of the flue, the boiler was remarkably well made, as well as all the apparatus belonging to it. It had two *safety valves*, two gauge cocks, and a glass water gauge. The foreman of the works, who had the superintendence of erecting both the boiler and the engine, (the latter being also new and of eight horse power,) was present and managing them himself when the explosion took place, he being also one of the unfortunate sufferers.

The verdict of the coroner's jury in the above case was "accidental death *occasioned by the insufficiency of water in the boiler*," which conclusion seemed to be arrived at, either from insufficient evidence, or inability to account for the accident in any other way; although there was direct evidence to the contrary, namely, that the gauge cocks indicated sufficient water a few minutes before the explosion, and that no steam was blown away in the interim. In concurrence with the opinions of the jury were those of several most respectable engineers, but with the addition, by some of them, of ascribing the explosion to the *sudden formation of hydrogen gas*, by the injection of cold water upon the supposed red hot flue when the engine started. This last opinion is far from being a singular one in many similar cases of explosion that have occurred with high pressure boilers, but is, as we think, a very erroneous one, not to say fatally so, in many instances. For by thus assuming a theory which, to say the most for it, is, according to our ordinary knowledge of the laws of chemistry, extremely improbable, a check is, to a certain degree, placed upon any further investigation, while the real errors of construction are perhaps kept out of view or repeated in other cases.

289. Now, if instead of the flue the *boiler* itself had been *oval* and the *flue circular*, the same means of obtaining a greater depth of water over the flue would have been afforded, but with much greater safety from explosion or collapse. For although an ellipse or oval is a weaker shape for a boiler than a circle, still from the pressure being *inside the curve*, any extra strain or pressure that the boiler may be exposed to, will only have a tendency to alter the curve into a stronger shape than it was before, or to approach more nearly to the circle. On the other hand, when the pressure is on the *outside of the curve*, the effect is exactly the reverse of the above, the strain having a constant tendency to put the curved surface into a weaker position; consequently, it follows, that a boiler slightly elliptical or oval in section, is, for all practical purposes, as strong as if it were circular; while, in an internal flue or tube, where the pressure acts externally to the arch or curved surface, if the curve is not truly circular, the tendency to give way and be crushed inward by what is called a collapse, will increase in an increasing ratio with the strain.

290. Hence it ought to be a rule in the making of high pressure boilers, that the inside flues, besides being circular, should also have their plates quite as thick, if not thicker, than the external shell or case. The boilers themselves may be to a considerable extent elliptical, even so much as in the proportion of 6 to 8, without materially diminishing their ultimate strength. Contrary, however, to the above recommendation, we frequently see a different practice followed, that is, the dangerous one of making oval inside flues of thinner iron than the boiler. If the peculiar form of boiler should in any case absolutely require oval flues, which may possibly be allowable for low pressure, those parts ought to be carefully supported by stays.

ON EXPLOSIONS CAUSED BY IMPROPER POSITION OF THE HEATED SURFACE.

291. An attentive perusal of the section on the position of the heating surface (in Chap. III. Art. 120, &c.) together with the preceding sections of the present chapter, besides bearing in mind what has been hitherto generally known on this subject, will, it is to be hoped, enable us to eliminate all the causes that were ever concerned in producing explosions of steam-engine boilers; and perhaps also put us in a condition to assist, if not in preventing, at least in placing some check to, the increase of those lamentable occurrences, and thereby tend to the removal of the only remaining barrier of any consequence to the further progress, and eventual complete triumph of the empire of steam.

292. There are only two ways in which a boiler can be made to burst or explode by the power of steam. One is by a gradual increase of the pressure produced in the usual way, but at a time when all egress is prevented until the steam acquires sufficient strength to force its way out by a rupture of the material of which the boiler is made. The other way is by some *sudden* increase in the quantity or pressure of the

steam, to such an extent, that the ordinary safety valves, or perhaps any other means of outlet that might be devised for the purpose, are unable to carry it off with the requisite rapidity for preventing any (although but momentary) strain greater than the boiler can bear. We have long been of opinion that it is in the consideration of the last of the above two classes of causes principally, that we ought to look for the proper remedy.

293. It will be recollected by those who read the newspaper accounts of the second explosion on board the Victoria steamer last summer, that great stress was laid upon the peculiar nature and situation of the injured portion of the boiler, the principal place of fracture being the lower part of the inside flue or tube by what is called a collapse of the flue *upward*. The boiler was on the circular or Cornish principle, that is with the fire place inside the tube, which was slightly elliptical, but of a very large size, so as to allow of merely a shell of water between it and the external case. Moreover, this boiler contained an inner tube within the flue tube, containing water, and communicating by means of short pipes with the upper part of the boiler, similar to some that have been lately introduced in Cornwall, therefore it has been called the "improved Cornish boiler." The boiler in this case had return flues underneath its bottom, and set up somewhat similar to the ordinary manner in which a Butterly or Cornish boiler is set up for mining or factory purposes,—a highly objectionable method, in our opinion, when applied to a steam vessel; and we have no doubt of being able to shew that this assisted in the production of the fatal catastrophe which took place in the Victoria.

294. A collapse of the flue upwards is not an uncommon occurrence in factory boilers that contain inside flues with rather flat bottoms; and it frequently occurs with what are called Butterly shaped boilers, or those which have the

mouth of the inside flue a very flat oval, particularly behind the bridge where the fire first passes into the tube.

On this particular portion of the bottom of the flue of a Butterly boiler, and for a considerable distance beyond the bridge, we have known small coal and coal dust to accumulate into a heap of some magnitude. Now with a pretty strong draught, and the flame reverberating downwards, as it necessarily does in both the Cornish and Butterly boilers, this heap of coal dust occasionally takes fire and burns with more or less intensity according to circumstances,—never perhaps with sufficient intensity to make the iron any thing like approaching to a red heat in the first instance, but rather gradually to deteriorate and weaken the iron in the manner we have before pointed out, in the case of the side plates of the furnaces of marine boilers; excepting that in this case the injury is more rapidly effected from the circumstance of the bubbles of steam which rise from the lower heating surface coming continually in contact with the bottom and sides of the inside flue; thus, in some measure, preventing the water from carrying off the undue heat accumulated in the iron plate above it.

295. We have occasionally met with instances where the mischief done in the above way was first evinced by the bottom plates of the flue being so far weakened or softened as to give way to the pressure of the steam sufficiently to form a dish-like protuberance within the flue, and consequently a corresponding concavity on the under side or that next the water, into which the steam would of course accumulate or become locked in the manner described in Article 152, &c. Now, after the injury has proceeded thus far, it is very evident that a second accumulation and ignition of coal-dust, may cause the injured part to become rapidly red hot, or sufficiently so as to cause the flue to burst upwards with the ordinary pressure of the steam, and this effect is in fact what frequently takes place. We have had many opportunities of

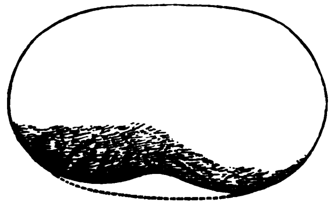
tracing the symptoms indicating the above effects, from their source, as above stated, to their full development in an explosion; and in one particular boiler in Manchester, this occurrence took place twice exactly in the manner above described.

296. That similar causes would produce similar effects in the Victoria boilers we have no occasion to contend, the principles of their construction being the same as we have briefly described above, the details of which any one may see by referring to the engravings of those boilers, published in the Civil Engineer's Journal, and also in the Mechanic's Magazine for last year.

The evil in all such cases arises from the principle (whether incidental or designed) of *heating water downwards*, which is essentially bad, and respecting which we have largely expatiated in various parts of this work. But our present business being principally with land or factory boilers, we have only to state that the evil is usually prevented by keeping the flues well cleaned out; but it would be better still, perhaps, to cover the bottoms of the flues with fire bricks, or a coating of Roman cement, or any substance that is a bad conductor of heat.

In the particular case mentioned in the last Article (295), the flue was about five feet by three, and assumed the following form (fig. 22) previous to bursting the first time;

Fig. 22.



the dotted line shewing the original position of the bottom plates. The plates were about 3-8ths thick, and the pressure 9 or 10 lbs. per square inch.

ON SAFETY VALVES AND SAFETY PIPES.

297. Formerly, when a *condensing* engine was spoken of, it was always considered that a *low pressure* engine, either Newcomen's or Boulton and Watt's, and working at only two or three pounds above the pressure of the atmosphere, was the kind of engine meant. But of late years, since the Cornish fashion of first expanding and then condensing high pressure steam has come into use, the terms used are no longer convertible.

More recently, owing to the great improvements made in engineering tools and workmanship, Trevithick's high pressure non-condensing engine has been made in such perfection, that it is frequently capable of working well at a *lower* pressure than even the Boulton and Watt low pressure engine is sometimes working at in the factory districts. Consequently there is some fear of a confusion of terms in those various designations, not perhaps when applied to the engines themselves, but with respect to their boilers. Thus, for instance, we sometimes see accounts in the newspapers of high-pressure boilers being *blown up* or exploded; and of the low-pressure boilers of condensing or factory engines only *bursting*, while the latter may really have been working at a higher pressure than the former.

298. There are, however, one or two broad marks of distinction between the two classes of boilers, well known to all practical engineers, and terms expressive of those distinctions (*high* and *low* pressure) have grown into use from the original manner of working the two great classes of engines, Boulton and Watt's, and Trevithick's. These terms, we think ought to be adhered to, not only because they sufficiently indicate, to the public generally, the presence or

absence of great danger, and correctly so when properly used, but also because it is probable that that portion of the working mechanics of this country usually entrusted with the care of steam-engines will continue to adhere to what has been sanctioned by long usage.

High-pressure boilers are universally known in England to be generally circular or cylindrical, or some form closely approaching thereto, and with hemispherical ends, (technically called *egg* ends,) unless the boiler contains an inside flue, and then the ends are only segmental or slightly convex,—but in all cases made without sharp corners or acute angles, and with iron plate of sufficient thickness not to require any internal stays to strengthen it.

Low-pressure boilers are not limited to any particular form, but so contrived as to suit the place they have to stand in, or that form which is most convenient for applying the fire to the most considerable portion of their surface. And the more they differ from the circular or cylindrical form, the more they require internal stays to support them, not only against the internal pressure of the steam, but also against the external pressure of the atmosphere, in case the steam should at any time happen to fall below that pressure.

299. To provide against the partial vacuum which produces the last mentioned effect, low-pressure boilers are also usually supplied with an air valve, sometimes called an *internal safety valve*. It is a small valve opening inwards, and weighted with only a few ounces, so that should the steam fall ever so little below the external pressure, it opens and allows air to pass into the boiler.

On the contrary, the high-pressure boiler is supplied with an *external* safety-valve, weighted so as to blow off at a little above the pressure that the engine is calculated to work at, which should never be more than one-third of that which the boiler has been proved to be able to sustain.

There ought, indeed, to be two safety valves, one locked up, loaded with the proper weight, and without the intervention of a lever; the other under the engineer's control, with a lever and spring balance indicating upon a scale the pressure exerted upon the valve to confine the steam.

300. The great and leading distinction, however, as respects danger, between the high and the low pressure boiler, is, that usually the former requires to be supplied with water by a force pump worked by the engine, and which injects a small quantity at every stroke against the elastic force of the steam; while, on the other hand, the low pressure boiler is supplied by means of a *feed pipe* standing on the top of the boiler, and containing a column of water of sufficient weight to balance the pressure of the steam, the water in the boiler being constantly supplied so as to retain the proper altitude, from a small open-topped cistern on the top of the pipe, which cistern is kept supplied either from the hot well by the engine or from any other source.

Now, as the feed pipe of a low-pressure boiler is only required to be of sufficient length to hold such a head of water as will, by its hydrostatic weight or pressure, balance the greatest elastic force of the steam intended to work the engine, it is evident that as soon as this limit is exceeded, the water in the feed pipe will be liable to boil or prime over, and, consequently, under such circumstances, the boiler becomes as perfectly safe as any ordinary open-topped pan of the same height as the top of the feed cistern.

301. From the above description we see the inutility of a safety valve on a low pressure boiler, except for the purpose of blowing off the steam occasionally, and thereby preventing the inconvenience resulting from boiling over; and this is accomplished generally by means of a valve

placed on the steam pipe leading from the boiler to the engine, so as to be at hand for the engineer to blow off when required, previous to stopping the engine.

Many people we know strongly recommend a safety valve to be placed on the boiler itself in addition to the ordinary blow valve of a low pressure boiler, but in the case of a boiler fitted up in the manner we have described, any one may perceive it would be perfectly useless, *and, therefore, practically injurious.* In saying this, it is not, of course, to be understood that any harm can accrue from an extra safety valve abstractedly considered, but only as it is a means of withdrawing attention from other more obvious means of safety. In this view of the subject the safety valve may be aptly compared to Sir Humphrey Davy's celebrated safety lamp for coal mines, of which it is frequently said, and we think truly, that for every life it has saved it has been the means of destroying twenty, by inducing a negligent attendance to improved systems of ventilation.

302. The common feed pipe of a boiler is, in fact, a *safety pipe*, and very much superior in all respects to any safety *valve* that can possibly be devised, the moveable column of water within the pipe answering the purpose of both valve and weight; and it is justly considered as a beautiful example of the general superiority and simplicity of using hydraulic means in accomplishing objects of this kind, over the ordinary mechanical contrivances. In the most improved arrangement for this purpose, (we allude to Mr. Elsworth's hydraulic joint for superseding the stuffing box of the buoy-rod, Fig. 23, Art. 306,) if considered as a safety valve, there is this essential property, *it cannot be overloaded* or tampered with in any respect; besides, it is impossible for it to *stick* or get out of order, because it is continually on the move, and that without wasting any steam.

303. Until within the last two years there were probably 400 to 500 boilers working in Manchester without safety valves, but nine out of ten of them, at least, were fitted up with the common feed pipe as above described; yet the proportion of fatal accidents from explosions of boilers in Manchester are almost as nothing in comparison to the number that occur in steam boats, although, in the latter, the boilers are always supplied with at least one safety valve.

The fact is, that, both in high and low pressure, the chance of an explosion occurring is more dependent upon the mode in which the boiler is supplied with water than upon any thing else, and although the common feed pipe is not so applicable in steam boats as on land, yet a safety pipe acting on the same principle might be very easily applied, and would serve as an infallible check against the water getting too low as well as against the steam getting too high, if made with its lower end to terminate a little above the flues, so as to allow the steam to blow away whenever the surface of the water in the boiler descended below that point.

304. A patent safety pipe has, we understand, been tried in London, but it is so contrived as to *put out the fire*, by boiling over into it, whenever the steam gets too high, which property would be perhaps in many cases an inconvenient addition, although not half so bad as an American safety pipe which has very recently been puffed through all the newspapers, and which is described as having the following curious property: *when the steam is too high it shuts the furnace door quite close, so as to make it impossible for the fireman to open it* to supply more fuel. Now if this patent contrivance had been made to act quite the reverse, or to have *opened* the furnace door as we do in England, instead of *shutting* it, the invention might have been useful; but as it

is, it is much more calculated to cause explosions than to prevent them.

305. We shall now conclude this Essay by an account of a well-known feeding and safety apparatus, which makes the bursting of any boiler to which it is attached perfectly impossible from the steam getting *gradually* too high or from the water getting too low.

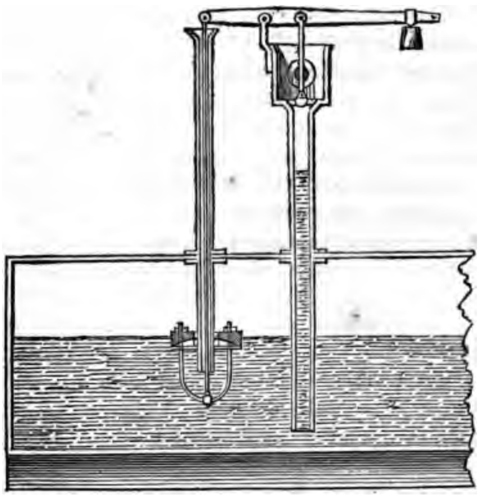
This apparatus was only briefly alluded to in the last edition, as we considered it to have been so well and so long known that no one having a steam engine could be ignorant of it, but in this we have found we were mistaken, as numerous applications from various quarters have been made, desiring a more particular account of it. Consequently, we have in this instance, considering the importance of the subject at the present time, departed from our original intention of reserving an account of that and all other steam boiler apparatus for a separate work.

On application to Mr. Hick, who is the principal maker of the apparatus, as to any improvement that he might have effected in it since its first invention, that gentleman has kindly referred us to a description of it written by him and published in Jamieson's Mechanical Dictionary, in 1828, (Article, Steam Engine). The apparatus, as there described, is exactly the same as is now usually constructed by him, and which we know to work admirably. The same article contains detailed drawings with description of the best 12 horse portable condensing engine, boiler, &c., that we ever met with; it also contains a description of Mr. Hick's spherical safety valve, which for all high pressure boilers and boilers in steam boats ought to be considered indispensable.

306. The following cut (Fig. 23) represents a longitudinal

section of part of a boiler, with the above-mentioned feeding apparatus attached; in which it will be seen that the rod which supports the buoy, or float, passes down through an open pipe containing a column of water the same as in the feed pipe, which water thus forms a hydraulic joint without friction, instead of the rod having to pass through a stuffing box on the top of the boiler.

Fig. 23.



Mr. William Elsworth, Civil Engineer, Preston, the original inventor of the above excellent contrivance, informs us that he first applied it to a boiler at the Moss Factory, belonging to Messrs. Horrockses, Miller, and Company, of that place, in 1816, and where it is still at work.

NOTES.

NOTE 1. CHAP. I. ART. 42. PAGE 33.

Smoke Burning.

SINCE this Article was printed, it has been ascertained that at least one half of the saving to be derived from the use of Mr. Cheetham's patent smoke burner, arises from the circumstance of keeping the ash-pit constantly closed up, thereby preventing any indraught of cold air through the flues during the night or at other times when the engine is not working. This is a most important part of the economy of the process, and is called by some gentlemen of Staleybridge connected with the patent, "*bottling up the heat.*" Of course this part of the invention can easily be used at all times when the engine stops, independently of that for the combustion of the smoke, and it has now been so used in several instances. I have been informed by a manufacturer*, who has proved it experimentally on a large scale, that the saving to be effected by this part of the invention, is about 12 per cent. Nothing can be more satisfactory than the mode in which this gentleman conducted his experiments. His plan was to work his boilers a whole week from Monday morning to Saturday night with the apparatus attached to all of them, (13 or 14,) and the succeeding week without the apparatus, and so on alternately for a great number of weeks, noting the consumption of fuel at the end of each. The correctness of these experiments was sufficiently proved by the fact of the saving remaining constantly the same, or at least not varying more than one per cent. on each side of the average of 12½.

The specification of the above patent may be seen in Newton's London Journal of Arts, Sciences, &c., for April 1839. As a *bonâ fide smoke burner*, it may be stated to have been, when carefully applied, more generally successful than any other that has been introduced in the manufacturing districts. I intend investigating the merits of this and other plans for consuming smoke in my forthcoming work on Chimneys and Furnaces.

The practice of closing up the ash pits of steam engine furnaces, except a very small portion at the upper part nearly close under the front of the fire grate, is very common, and I have long recommended it as the

* John Leech, Esq., of Staleybridge.

best means of causing the fuel to be consumed on the front of the grate as quickly as at the back, thereby keeping the fire of a uniform thickness; but to effect this object in the best manner, the opening is required to be of the full width of the fire grate, so as to allow a thin stratum of air to pass nearly horizontally to the under side of the fire bars, and then, by properly adjusting the height and the area of this opening, the air can be caused to impinge nearly uniformly on all parts of the grate.

It is very easy to use this opening to the ash pit as a regulator for the fire instead of the damper, but I consider that it is highly objectionable to do so, although it is recommended by Tredgold and other authors, besides having been recently put into practice in some of the Atlantic steamers. One of my reasons against using the opening in this way, is, that there can be only *one* position of it, which is the best for the particular furnace and system of firing it is used with,—this, when once found, of course necessarily excludes any alteration without liability to injury. Besides the *quantity* of air admitted can be quite as easily regulated by the damper in the chimney flue. The damper in fact ought to be confined exclusively to the purpose of only regulating the quantity of air admitted, so as to suit the varying demands of the engine for steam; while the ash pit regulator is used for giving a proper direction to the current of air, and also to shut the latter off entirely.

When the ash pit regulator consists of an aperture and sliding plate of six or eight inches square in the centre of the front of the ash pit, it is then perhaps of the worst possible kind, as it causes the air to act on the centre of the fire like the concentrated blast of a blow pipe or bellows, and most destructively on some particular portions of the boiler, which as well as the grate bars becomes very speedily burnt out. This effect, however, is not so liable to be produced in the case of factory boilers, or those which are fired by machine and have moveable bars, as it is in that of locomotive and marine boilers. The latter are more especially liable to become burnt out in this way owing to the usual system of firing pursued in steam vessels, and which is very properly called *charging* the fires,—the operation being in fact more like that of charging a retort for making gas than any thing else.

It is unnecessary to repeat here opinions expressed in the body of the work in favour of thin fires and quick combustion for land boilers, as it may be said to be a point yet open to discussion; the system of *slow* combustion having lately received a talented advocate in the author of a paper read before the Institution of Civil Engineers last winter*. But

* This paper has been published separately by Mr. Weale, as Part I. of Vol. III. of the Transactions of the Institution of Civil Engineers, entitled "On steam boilers and steam engines." By Josiah Parkes, M.Inst.C.E. 1839.

respecting the applicability of slow combustion to steam navigation, it is impossible that there can be two opinions amongst engineers. *A thin fire and a quick draught* are the great essential points to be attended to in steam packet boilers, and will always be synonymous with plenty of steam and a quick passage.

Mr. Josiah Parkes, who is the great propagator of the principles of slow combustion, admits that it requires about seven times the area of heating surface to produce the same evaporative effect by it as by the ordinary practice; a sufficient disqualification against its adoption in steam packets. It has been sufficiently proved, that, with the common Lancashire coal, a greater area of properly disposed effective heating surface than a square yard to each horse power is not advisable as a means of economy at the ordinary prices of materials and cost of management, in the case of land boilers in the cotton manufacturing district, or, in other words, any saving that would arise from an extension of the heating surface of a boiler beyond this limit, would be overbalanced by the ordinary interest for the outlay of capital and other contingent expenses in obtaining it. Hence, how outrageously absurd it is to expect to derive any great increase of profit from the adoption of the system of slow combustion in steam vessels, when we consider that not only are the boilers of the latter (from the necessities of construction) about double the weight and three times the cost of land boilers of equal power, but there is also to be reckoned the cost of carrying them, or the displacement of so much valuable cargo, although there is a set off against this to a certain extent, on account of the expense of carrying the extra coal or rather *half the coal* that would be saved by the enlargement of the boiler. This, however, is a matter of the simplest possible commercial calculation; for example:—if by doubling the size and weight of a steam packet boiler a saving in fuel can be effected of *five per cent.*, (a supposition which I by no means admit as probable,) and supposing the fuel to be consumed gradually from the commencement to the termination of the trip, then the proper deduction on this account for lightening the load of the vessel will be *two and a half per cent.*; while, on the other hand, what is saved in boiler room must be reckoned at its full amount as permanent available profit.—If calculated in the same manner, I have no doubt but that the much vaunted saving by working marine engines expansively will be found to be very small indeed, unless the steam is raised to so high a pressure as to become dangerous. Raising the steam to a dangerous pressure in the boiler merely for the purpose of expanding it again in the cylinder at a greatly reduced power,—as well as the system of slow combustion and wire-drawing the smoke through long winding flues in order to save a modicum of coals, are at best but philosophical niceties that are quite out of place in an Atlantic passenger steam ship in the present early stage of steam navigation. In short, wire-drawing the steam and wire-drawing the smoke, are in this case equally dangerous and useless, and the sooner steam packet proprietors dismiss them and attend more to a radical reform in the construction of their boilers, the quality of their coal, and the management of their fires, and, above all, to some more efficient means of propulsion than the present lumbering paddle wheel, the sooner they will accelerate the passage from Europe to America.

A slight consideration of the above principles, and a proper application of the rules contained in this work, will prevent any one getting so far wrong as some few influential parties connected with the commercial steam marine of this country have unfortunately had the means of doing; I say unfortunately, because extensive loss of life has already taken place, and must inevitably occur in future, in an increasing degree with the rapidly increasing number of steam ships for long voyages, unless the managers and engineers concerned unite a sound practical knowledge of the subject with a willingness to learn more from whatever source it may be offered, rather than the flippant parade of pseudo scientific acquirements that is sometimes to be met with, and which on application to new circumstances is always found to be miserably inefficient for any thing but failure.

The above sentiments are far from being meant to reflect invidiously upon any particular steam packet company, but, to a certain extent, they admit of a general application, and in excuse for saying this, I need hardly state that the subject is one of great public concern where the lives of thousands of passengers are daily intrusted to the care of hands wielding such an unseen and tremendous power as that of steam. With respect to the misapplication of capital and waste of property involved in the mismanagement of marine boilers, it may seem not a proper subject for animadversion, as the owners must in time "find it out," and some of them have commenced finding it out very speedily. As an illustration of this expensive way of trying experiments, it will be quite sufficient to mention the "Liverpool," which was the first steamer from Liverpool to New York belonging to the Transatlantic Steam Ship Company. In this vessel it was determined to try the celebrated Cornish principle of *slow* combustion, in order to burn the smoke, on her first voyage; this was effected by a misapplication of Mr. Parkes's principle, namely, *by allowing a constant stream of cold atmospheric air to pass into the flues of the boiler through a large aperture opening from the ash pit to behind the bridge of each furnace;* which aperture was *without a valve* or any other means of closing it at the discretion of the engineer. The consequence was, that although the engines, &c., were in every respect excellent, as well as the vessel itself, the latter after proceeding nearly half way across the Atlantic was compelled to return to Cork, where, of course, the patent smoke burning holes were stopped up before she proceeded again to her destination.

NOTE 2. CHAP. VI. ART. 274.

Theory of Explosions.

So true it is that there is "nothing new under the sun," that few people are to be met with who dispute the general application of the adage; but still fewer, perhaps, who are willing to apply it to their own ideas when the latter happen to be original with themselves. It is perhaps too generally the case that writers rather endeavour to keep every thing out of sight that would appear to trench upon their own claims to originality. By inserting, however, the following extract, it will be seen that I have no feelings of this kind. The writer is perfectly unknown to me, and, as will be seen by the date, his communication was published three years prior to the first edition of my book.

"STEAM ENGINE BOILERS.

"TO THE EDITOR OF THE SUNDERLAND HERALD.

"SIR,—In looking over your paper of the 15th inst., I observed some remarks by Mr. Graham, respecting the late melancholy accident that occurred at Mr. Henderson's manufactory at Durham.

"From the frequency and fatal results of accidents of this nature within a short period, I have been led to give some consideration to a subject of the highest importance to the engineer, the workmen, and the public. I am the more desirous of stating my opinions upon the present occasion, from the circumstance of the two engineers who were examined on the inquest having stated in their evidence, according to Mr. Graham's account, which from the circumstance of that gentleman being a juror, I assume to be correct, that it was impossible to assign a reason for the explosion, as every thing appeared to them to be right about the boiler.

"It appears to me, Sir, to be particularly worthy of observation, that nearly all the explosions we have had to lament for some time past, have occurred when the engine was standing. I do not remember one misfortune taking place when the engine was going. This, together with many other circumstances, and no short experience, have convinced me that to one or other of the three following causes may be attributed nearly all the explosions of steam boilers. If my observations should be the means of preventing, or even of lessening the number of those calamities, it will afford me the greatest satisfaction.

"The first cause, then, I consider to arise from the safety valve either being overloaded or made fast.

"Second—The boiler having been suffered to become foul at the bottom. Or,

"Third—A weak boiler.

"As I am decidedly of opinion that by far the greatest number of these disasters have occurred from the second reason given, 'a foul boiler,' I will now only request your attention to that particular point.

"The water with which most boilers are fed, usually contains siliceous, argillaceous, or calcareous earths, and other foreign matters suspended in it. These are gradually deposited upon the bottom of the boiler, where they form a coat or crust whenever the fire is lowered and the ebullition ceases. The first effect produced by this accumulation of matter, is to lessen the action of the fire upon the water inside the boiler, and to require more time to raise the same quantity of steam than would be necessary if the boiler bottom was clean.

"The next effect is, when the engineer is raising the fire the foul coating will rise in blisters of various sizes, by which the bottom plates will become red hot. The blisters, on their breaking, let the water down upon the hot plate, causing explosions of different degrees of violence, according to the magnitude of the blister. These explosions are similar to the report of a pistol, and take place every time the engine starts, or is preparing to start, after standing long enough for the mud to subside. They will sometimes even force down an iron plate or some parts of it, and on that particular spot where the indentation has been produced the mud accumulates thicker. In the event of these blisters being very large, on their bursting, the water will be forced into sudden contact with the red hot iron, by which a tremendous explosion is the inevitable result. No number of safety valves is an adequate security against the terrible effects of such a concussion.

"To explain this material circumstance still further: if a boiler be stopped half an hour or an hour, the man generally sets the fire doors open, and also puts a few coals on to damp the fire until the workmen are ready to commence work again. On the ebullition ceasing, the suspended matter in the boiler will nearly all subside in about ten minutes, and be deposited on the bottom of the boiler; and if the water be very foul, and the boiler bottom (or sides of some boilers) has not been cleaned for two or three weeks, it will then be a great thickness, and become thicker daily; consequently, every time the fire is raised, this accumulated mud on the bottom and sides must rise, and be completely incorporated with the water in the boiler before the steam can be raised and the machinery again set in motion.

"From the foregoing remarks, an interesting question naturally arises —'Is there a remedy, or are those lamentable catastrophes still to continue to hold their desolating sway over the unsuspecting manufacturer, the industrious workman, and the distant traveller?'

"I hope sincerely that some of your numerous readers will now be awake to the importance of this subject. Government, I see, has thought the explosions in coal mines deserving its notice. Steam boilers have probably caused as great a destruction of human life within the same period; and, therefore, seem equally deserving its attention. We hope the subject will be attended to by the legislature, and every engine-man compelled to keep his boiler both clean and strong.

"S. P."

"Heworth, Aug. 26, 1835."

THE END.

G. Woodfall, Printer, Angel Court, Skinner Street, London.

WORKS
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1.
STEAM NAVIGATION.

APPENDIX A.
TO
THE NEW EDITION OF
TREDGOLD ON THE STEAM ENGINE.

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Price Twelve Shillings.

⁎ Appendix B., containing text to both A. and B., will be published in the Autumn.

2.
THE PRACTICE
OF MAKING AND REPAIRING ROADS;
OF CONSTRUCTING FOOTPATHS, FENCING, AND DRAINS;

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