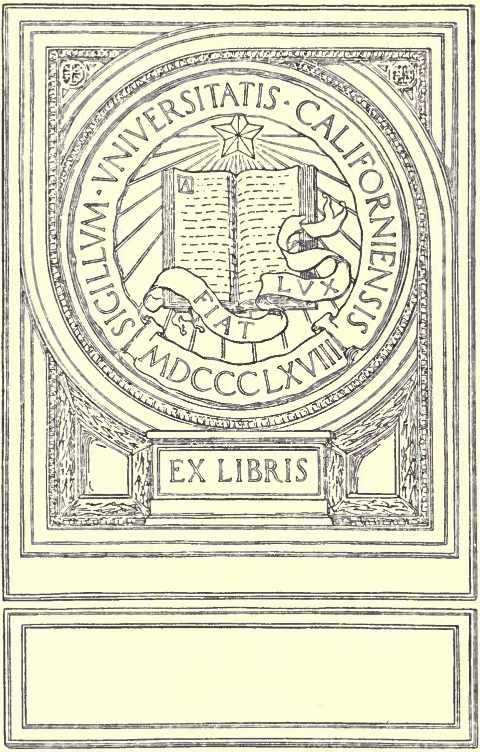
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# NOTES

ON THE USE OF

# ANTHRACITE

IN THE

# MANUFACTURE OF IRON.

WITH SOME REMARKS

ON ITS

## EVAPORATING POWER.

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# INTRODUCTION.

The object of the following brief notices of an important branch of our iron manufactures, is at once to record in a permanent form and in a connected view an account of the efforts which have been made in different quarters to accomplish the reduction of iron ores with anthracite, and to furnish to many interested inquirers that information which may, in some degree, guide future undertakings in this department of the useful arts. To the intelligent proprietors of the several works described in the following pages, the writer's acknowledgments are due for the prompt manner in which their several establishments, and, when desired, the records of their operations have been placed under his inspection.

A like acknowledgment is due to those scientific and practical gentlemen who have with so much liberality placed in his hands the results of experience on the heating power of anthracite and the various forms of boilers.

The few inductions which he has ventured to make, from the data herein detailed, will of course be received with a proper understanding of the number of facts on which they rest.

It has been the author's earnest desire to impart only useful information, and he has accordingly omitted all notice of trials on smelting with anthracite reputed to have been made in private, the results of which have not been deemed sufficiently important by their authors to give them publicity or to warrant a farther prosecution of their labors.

In a more extended work on the general subject of the manufacture of iron, for which he has been for some years collecting the materials, the writer proposes to place before the public, in a convenient form, both the scientific and practical information so much desired by all who are interested in the various branches of this important department of industry.

October, 1841.

# NOTES.

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Scarcely any branch of art is more intimately connected with the progress of civilization than the manufacture of Iron. The "precious metals" cannot be compared with this material in real value and usefulness. As it ministers to all those arts which convert other productions of nature to the purposes of man, it may claim to be the *right hand* of industry in all its forms and applications. The warehouse, workshop and dwellings of some countries are either supported, or covered, or wholly built of this metal. Floating structures, exceeding in magnitude the largest line-of-battle ships, are formed of iron, and urged by machines of gigantic proportions of the same material. The rigging and ground-tackle, not only of iron steamers but of many other vessels, are now constructed mainly of wrought iron. Our modern wonders of locomotion could not possibly have existed in ancient times. Furnaces and rolling-mills and machine shops, which could spring up only contemporaneously with large developments of the iron manufacture, were essential to the production of these astonishing results.

All who regard the manufacture of iron in the light above presented, must hail every improvement in its production with interest and pleasure ; and the application to this purpose of a material, which, a short time ago, was regarded as wholly useless in Europe, and of which America had then made but a limited use beyond domestic purposes, is naturally the subject of much inquiry and speculation.

The main object of the following brief account of this branch of the iron manufacture is, to state the facts, so far as known, relative to its introduction and present state, with such deductions as may be found useful in regard to the construction and action of the several establishments. The facts thus collected and collated may, it is hoped, serve in some measure as guides to future practice, and, at least, prove salutary indications of what is to be avoided in the application of anthracite to this important purpose.

A few years only have elapsed since the introduction of anthracite into extensive use for domestic purposes. A still shorter period has passed since it was held to be a moot-point whether or not this combustible could be used for generating steam; and even after numerous stationary engines, particularly in Philadelphia and its immediate neighborhood, had been using this fuel for several years, it was regarded by some as doubtful whether, in steamboats and locomotive engines, it could be substituted for wood. The problem of its applicability to the purposes of the founder, to melt iron in the cupola, has been settled affirmatively for some years — as have all the other points above referred to. For the forge-fire of the common blacksmith it has been extensively introduced. In our anthracite region no other fuel is used for this purpose; and for various manufactures, such as lime-burning, malting, &c., it has been put into considerable requisition. An object of not less importance, perhaps, than any of the preceding, is its employment in the smelting of iron ore in the blast furnace, and the converting of cast, into malleable iron, by refining, puddling and re-heating.

The making of iron with coke, so long practised in England, Scotland and Wales, as well as on the continent of Europe, can hardly be said to have yet come into practice in this country. A number of attempts have, it is true, been made to introduce this important branch of manufacture, and, as was very natural, the state of Pennsylvania, abounding throughout a vast portion of her territory with bituminous coal, in immediate contiguity with beds of iron ore and limestone, has been the scene of most of those attempts. The legislature of Pennsylvania, in 1836, passed an act for the encouragement of the manufacture of iron by mineral fuel, giving to the governor authority to charter companies with ample powers in regard to the amount of stock and quantity of land, for the purpose of prosecuting this branch of industry. In the same year, though not under the privileges conferred by this law, a quantity of iron was made with coke, by Mr. F. H. Oliphant, of Fayette county, who sent to the Franklin Institute samples of the metal produced, and of the various materials employed at the furnace. It is understood, however, that this gentleman does not continue the manufacture of iron by coke, probably from the higher value set upon charcoal iron, particularly for conversion into steel, which is carried on at his establishment. It is also probable that, in a region where wood is still abundant and mining labor scarce, the economy of using coke instead of charcoal may admit of some doubt, especially as the cost of machinery and power, to supply blast for coke furnaces, is generally greater than that required for charcoal.

During the years 1835–36 and 37, furnaces were erected at Karthaus and Farrandsville, on the west branch of the Susquehannah river, and at Frozen Run, near the Lycoming creek. At the first of these establishments, several hundred tons of pig metal were produced by coke, but for want of due discrimination in the selection, and care in the preparation of ores, the quality of the product was such as to render it unsalable, and the works had the farther disadvantage of being placed beyond the reach of the present state improvements, a circumstance, which rendered the transportation of supplies as well as of the metal, too uncertain and expensive. The furnace at Farrandsville was unfortunately placed in regard to the ore, the latter being brought by canal from Larrey creek and Bloomsburg, at distances of twenty and one hundred miles. The wealthy gentlemen, to whose liberal outlays the erection of this fine establishment is due, have, it is understood, come to the determination to dispose of the same, and thus to relinquish the honor which the friends of our domestic industry had hoped to see them achieve; namely, that of introducing the *profitable* manufacture of iron by means of the bituminous coal of Pennsylvania. The furnace at Frozen Run is well situated in regard to ore, having a three feet bed of yellowish white carbonate, as its principal reliance; but the beds of coal in the neighborhood have not proved so valuable for immediate use, as the heavy forests of timber growing above them; and hence the furnace was found at the last visit of the writer (September, 1839) to be using charcoal, and making therewith excellent pig metal. In this brief reference to coke furnaces in Pennsylvania, it would be unjust to omit mentioning that of Lonakoning, situated on George's creek, in Maryland, a few miles south of the Pennsylvania line, and in the rich coal basin lying between the Savage and the Little Alleghany mountains. When visited, in the beginning of June, 1839, this furnace was making about seventy tons per week of good foundry metal, and every thing betokened a successful prosecution of its operations.* It had, however, the misfortune to be situated remote from any available line of public works,

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* The principal bed of coal at Lonakoning is 14 feet thick, of which 9 feet are worked. The ore is in different seams, from 7 to 12 or more inches thick. The limestone is four feet thick. All the materials are found at higher levels than the trunnel head of the furnace. The furnace has a diameter of 14 feet at the boshes, which slope back 6 1-3 inches to the foot of rise. The ore yields 33 per cent. of iron. The blast is supplied by a steam engine, of which the cylinder has a diameter of 18 inches, and an 8 feet stroke. The steam is generated in five boilers, 24 feet long and 36 inches in diameter, at a pressure of 50 pounds per square inch. The number of revolutions per minute was 12. The cylinder for blast is five feet in diameter, and of the same length as the steam cylinder, viz. eight feet; the same piston-rod extending through both cylinders. The quantity of blast was 3770 feet per minute, under a pressure of 2 or 2 1-2 pounds per square inch; demanding at the latter tension, a force of 50.9 horse powers. The engine is capable of exerting a force of 74 horses. It injects daily 181 tons of air in making 10 tons of pig iron, and burning the coke from 50 tons of coal.

and accordingly the expense of bringing its products to market, has paralyzed its operations.

On the south branch of Jennings's Run, a few miles north-eastwardly from Frostburg, and in the same coal basin with Lonakoning, two large blast furnaces, on the Welsh plan, for using coke or bituminous coal, are now in progress.

In contrast with this slow progress and languishing state of the coke establishments, we find that within little more than three years, the anthracite furnaces have commanded the attention of many enterprising parties, and that already not less than eleven or twelve, have, in Pennsylvania, been devoted to the prosecution of this manufacture. Three or four more are in contemplation, and will doubtless be speedily erected. Four are either finished or in progress at Stanhope, on the line of the Morris canal, in New Jersey. Those who have clearly understood the character of anthracite, as being the most dense form of mineral fuel, have long perceived the importance of applying it to the smelting of iron. Its comparative freedom from waste by transportation, and its little liability to change by atmospheric influences, have marked it as singularly favorable for use *in furnaces at a distance from the place of its origin.* But the more recent developments in the anthracite formations have proved that it is not, in general, necessary to resort to the expedient of carrying either the coal to the ore or the ore to the coal, in order to be able to make iron with anthracite. If either of these courses of transportation were really necessary, the former would for the most part be preferable, because the weight of ore necessary to produce a given weight of metallic iron, is in general greater than that of the anthracite required for its reduction. Thus, of the rich fossiliferous ore of Bloomsburg, from 2 to 2 1-4 tons are required to make one ton of iron, while of Wilkesbarre anthracite, from one ton and ten to one ton and twelve hundred weight is the quantity demanded, including what is necessary for heating the blast. When it becomes necessary to use anthracite to produce steam power for blast, the amounts of coal and ore are nearly equal, and the propriety of one or the other course of conveyance, would then be determined by other considerations.

But, to return to the uses of anthracite; it is not merely in the smelting of ores, and the production of pig metal, that our iron manufactures are now affording a profitable employment of this fuel. It has been satisfactorily demonstrated, that the processes of puddling, boiling, and, in subsequent stages of the process, that of heating blooms, slabs and billets, can all be effected by this fuel alone. This, in fact, with its use in the smith's fire, carries the metal through every stage, from the ore to the manufactured article, with no other fuel than anthracite.

As above hinted, our anthracites are like our bituminous coal deposites, largely intermixed with iron ores, hitherto much neglected; and hence the establishment of anthracite ironworks in Pennsylvania, with the exception of limestone, involves no question relative to the cost of transporting the raw material. The methods of boiling and puddling with anthracite have, it is believed, like the smelting of ores with the same fuel, been first invented in this country.* They will doubtless be applied

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* Dr. Geisenheimer's patent for smelting iron with *anthracite and hot blast*, was taken out, we believe, before any thing was effected, in that way, in Wales. This patent is understood to have been bought up by Mr. Crane, and is believed to be the only one, if any, which can avail against the public use of this process in the United States.

This patent of Frederick W. Geisenheimer bears date 19th December, 1833. We take from it the following

EXTRACT FROM THE SCHEDULE.

" Claims. *First* — the application of anthracite coal, exclusively or in part, in deoxidating and carbonating iron ore as above specified and described.

*Secondly* — the application of anthracite coal, exclusively or in part, in combining iron, in a metallic state, with a greater quantity of carbon ; if bar iron for steel, if pig or cast iron for a superior quality, as above specified and described.

*Thirdly* — the smelting or reducing of iron ore, so deoxidated and carbonated by the application of anthracite coal as aforesaid, into pig or cast iron.

*Fourthly* — the refining or converting of iron ore, so to the conversion into bar iron of other pig metal than that smelted with anthracite, and thus a large demand for the combustible cannot fail to be created.

Among the earliest attempts to use anthracite for smelting iron, may be mentioned that of certain members of the Lehigh Coal and

deoxidated and carbonated by the application of anthracite coal as aforesaid, into malleable or bar iron.

*Fifthly* — the application of anthracite coal as fuel, in smelting or reducing iron ore raw or roasted, but not prepared by a previous separate process of deoxidation and carbonation as above described, into pig or cast iron.

*Sixthly* — Though I cannot and do not claim an exclusive right of the use of heated air for any kind of fuel, nevertheless I believe to have a right to claim and do claim the use of heated air, applied upon and in connexion with the said principle and manner discovered by me, to smelt iron ore in blast furnaces, with anthracite coal, by applying a blast of air in such quantity, velocity and density, or under such pressure, as the compactness or density and the continuity of the anthracite coal requires, as above amply and fully described and illustrated." [*Dated at the city of New York, on the twenty-first day of November*, 1833.]

Navigation Company, who, in the year 1820, erected near Mauch Chunk a furnace, intended for that purpose. This was anterior to the establishment referred to in the annexed table, under the name of Mauch Chunk furnace. The first attempt on the Lehigh resulted in nearly the same manner as did a similar trial at Vizille, on the borders of France and Switzerland, under the charge of MM. Gueymard and Robin, where it was attempted to use anthracite either alone or in connexion with other fuel. This last, it is well known, was abandoned in despair of rendering, by this means, the manufacture of iron profitable, and the outlay of one or two hundred thousand francs was set down to the debtor side of profit and loss.* As no succinct account of those

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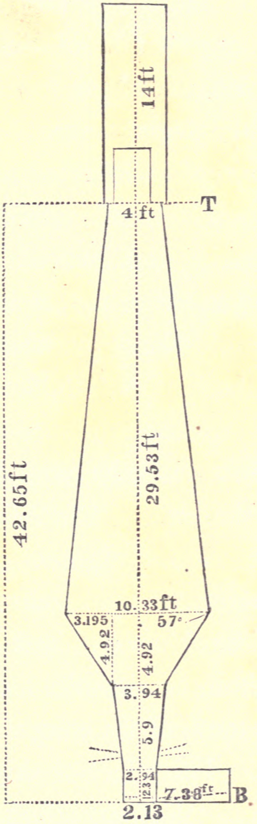
* An account by M. Gueymard, of the commencement, progress and result of these experiments, was published in the Annales des Mines, vol. iii., 3d series, p. 71; and in the 4th volume of the same work, same series, is contained another account of the same trials, by M. Robin, by whom a part of the experiments were superintended. The latter describes the furnace.

trials has probably been published in this country, it will, perhaps, not be unacceptable to the reader to have the following statements placed, either for instruction or warning, in connexion with our account of what has been accomplished in the United States.

M. Gueymard justly remarked that, at the period when the trials at Vizille were made, no precedent existed by which to solve the most difficult and, perhaps, the boldest problem which the excitements of industry throughout France, for the three preceding years, had called into notice. England had exhibited only two fruitless attempts to smelt iron with anthracite; and in these it was found that, as long as the proportion of anthracite did not exceed one fifth of the whole fuel, the furnaces continued to work as usual, and the iron remained grey; but beyond this limit the pig became white, the furnaces chilled and were in danger of choking.

In making the experiments at Vizille, every appliance then at the command of the iron manufacturer appears to have been brought to bear upon the success of the undertaking. The stack was of ample dimensions and approved form, corresponding, as will be seen on inspecting the sketch given below, with furnaces elsewhere employed with success in using coke. It was 10 feet 4 inches across the boshes, 42 feet 8 inches from the bottom of the hearth to the trunnel head, with a chimney 14 feet above the latter; and the pitch of the boshes was 57°. An engine of 80 horse power was employed to furnish blast, the pressure of which was sometimes urged as high as 4 lbs. to the square inch. The number and size of the nozzles were varied to suit the exigencies of the case. Care had been taken to avoid the destruction of the hearth, boshes and inwalls, by forming them entirely of the best fire-brick. The blast was commenced with coke from the coal of Rive-de-Gier, and, with this fact, of which 10.71 per cent. were ashes, excellent foundry iron was produced.

The accompanying sketch, on a scale of 3-4 inch to ten feet, exhibits a section of the interior of the furnace at Vizille, in which were made the experiments on smelting with anthracite, in 1827–8. From the bottom of the hearth *B*, to the trunnel-head *T*, the height



was 13 metres, or 42.65 feet. The square, (*creuset,*) was a parallelopiped, 7.38 feet long, 2.13 feet wide, and 2.3 feet high. From this rose the working section of the hearth, (*ouvrage,*) in which, above the top of the square, were placed the blast tuyeres. This section was in the form of an inverted truncated cone, 5.9 feet high, 2.13 in diameter at the bottom, and 3.94 at the top, where it joined the boshes, (*etalages,*) which were in the form of a truncated, eight-sided pyramid, 3.94 feet in diameter at the bottom, 10.33 at the top, and 4.92 feet in vertical elevation, — thus making the whole height, from the bottom of the hearth to the top of the boshes, 13.12 feet, or exactly 4 metres.

When the furnace had been brought to a good state of working with coke, the first experiment with anthracite was made by substituting for one tenth of the coke an equal weight of anthracite. The effect of this change was to render the metal, if any thing, rather better than before, and only to retard slightly the descent of the charges.

With two tenths anthracite the result was very nearly the same, or with but a little more retardation.

Three tenths of anthracite gave a still further retardation, but the iron and cinder both continued good, only a trace of iron being found in the latter.

With four tenths of anthracite a still further retardation in the speed of descent occurred, and the furnace began to be clogged, preventing the penetration of the blast, and causing it to find vent beneath the tympe arch, projecting out portions of red hot cinder.

The slow descent of charges occasioned the refining of some of the cast iron on the slope of the boshes, deranging, in some degree, the working of the furnace. The cinders changed color in proportion to the unreduced iron retained in them. The metal had no longer the same beautiful grain as at first, but became greyish white, mixed and irregular, and subsequently mottled, and white, as the working became worse.

The anthracite was, after some days, increased to one half. A new retardation was at once perceived; cinder was thrown out not only at the tympe, but even at the tuyeres. These experiments were for a time interrupted by a fatal accident, which crushed to death a workman in the bottom of one of the blowing cylinders, and deranged the whole machinery.

The results hitherto obtained, were, the production of foundry iron by anthracite and coke in the proportion of one half of each; the hard working of the furnace, the slow descent of charges, the making of about two tons of iron in twenty-four hours, and the running of good cinders until the furnace became deranged. The proportion of fuel was from three to four hundred weight for one hundred of pig metal produced.

The blowing machine having been repaired and the hearth renewed, the furnace was again put in blast on the 19th of January, 1828.

The operations were now commenced with one half anthracite and one half coke, in order to continue the preceding experiments. Efforts were made to prevent the blowing out of cinders, the accumulations on the boshes and the slow descent of charges. One, two, and three tuyeres were successively used; the size and position of the nozzles were varied, as well as the number and proportion of charges, but without the least gleam of success. An illness of some days having detained Mr. Gueymard from the works, the anthracite was in the mean time entirely suppressed, and coke only employed. In less than four days the furnace had resumed its wonted action, and the products became perfectly satisfactory, as at the beginning.

After Mr. Gueymard's recovery, the course of trials with one tenth, two tenths, &c. to five tenths of anthracite, were resumed. The previous results were reproduced, and all the expedients to overcome the evils were unavailing. The anthracite burst and fell into fine pieces, which choked the furnace and obstructed the blast. In this state of things the expedient was adopted of charging the furnace with raw instead of roasted mine, which had the effect of keeping the burthen from cohering, allowed freedom to the blast, and obviated the projection of cinders from the tympe and tuyeres. The iron became as good as at first, and equal to the best English pig metal.

The proportion of anthracite was then increased to six tenths. The furnace still worked well, with the exception that the load came down rather more slowly than before.

Seven tenths of anthracite, gave the same working and the same cinder, but a still greater retardation, and a tendency in the pig to a mottled complexion. The charges were next carried to eight tenths anthracite. The pig became entirely mottled or white, for eight days, during which this rate of charging was continued. The action was yet more sluggish than before, but as the working was still easy, they proceeded to nine tenths of anthracite and only one tenth of coke. Two days after this proportion was adopted, the projection of cinder recommenced, as well as the lodgements on the boshes, and a chilling in the hearth, which made alarming progress. Eight days were likewise consumed in determining the effect of this mixture. The force of blast, number of tuyeres, size of nozzles, &c. were varied, but no other than white metal could be obtained, and even that ran very stiff and pasty.

As the committee of proprietors in Paris wished to have the experiments pushed to the utmost, M. Gueymard finally ordered the furnace to be charged with anthracite alone. From the moment this was done, the tuyeres became and continued black; the cinder was surcharged with iron, no casting could be obtained; the metal half refined into malleable iron, stuck fast in the hearth. It was white semi-ductile, and had all the characters of "*fine metal.*"

On returning to seven tenths anthracite, the going of the furnace was soon re-established, and the charges were kept down to within thirty or thirty-one feet of the bottom of the hearth.

The coming down of the charges was not, however, accelerated. The pig became mottled, and the working hard. Hence it is inferred, that a lower furnace would not solve the problem.

When the furnace was driven with coke only, the manometer gauge of the blast stood at 3.15 to 3.54 inches of mercury, indicating from 1.5 to 1.75 pounds per square inch.

When the charge was *seven* tenths anthracite and three tenths coke, it required from 2.95 to 3.15 pounds of pressure for grey iron, 2.75 for mottled, and 2.56 for white.

With a higher proportion of anthracite, the pressure required was about *four* pounds per square inch.

With pure coke, the number of charges was from 40 to 42 in 24 hours.

With one half anthracite, the number of charges was reduced to 25 per day. With *seven tenths* but 20, and with anthracite alone, but *six* per day could be passed.

From the above statements it will be seen, that, whatever can be expected from anthracite of the kind there used, when burned by means of cold blast, was probably realized in the experiments at Vizille. It is certainly possible that, in our Pennsylvania anthracite fields, passing, as they are known to do by slow degrees, from the extreme dryness of the most compact anthracite, at one end of the coal trough, to a decidedly bituminous coal, with from 12 to 18 per cent. of volatile matter at the other, we may find some intermediate varieties to which the cold blast may be found applicable for the smelting of iron, though the coal be not susceptible of *coking*, and therefore belongs to the class of *anthracites*. Yet the general character of this class is so well represented by the kind used at Vizille, that it appears unreasonable to expect any other result than that to which the French experiments conducted. In those parts of the same coal-fields where the bituminous nature of the mineral is fully established, there seems to be no reason to doubt that the cold-blast and raw-coal system of Dowlas and other Welsh iron-works, may be found entirely applicable. But the French experiments, as well as those previously and subsequently made in Wales, together with those which were undertaken at

Mauch Chunck and at Pottsville, before the application of Dr. Geisenheimer's improvement, are salutary cautions to persons who may be inclined to attempt the smelting of iron by true anthracite and cold-blast.

Having, in the preceding pages, referred in general terms to the efforts made to introduce the use of anthracite in the blast furnace, we may pass to a more detailed description of those establishments which have been erected in the United States for manufacturing iron by the method in question. For the greater facility of comparison, it has been thought best to convey this information in the form of a Synoptical Table.

It will be perceived that, at three of the establishments, viz., Mauch Chunk, Montour No. 2, and Shamokin, the columns devoted to the weekly supply of materials are in blank; the first, because it had ceased to operate at the time the other data relating to it were procured, and the records of its daily action could not be obtained, and the other two had not then gone into blast. Of these, therefore, only those columns which relate to the construction are filled. In regard to the other establishments, the *observations*, which would properly constitute the last column of the table, are, from the necessities imposed by mechanical arrangements, thrown into separate sections in subsequent pages. It is only necessary to mention that, in obtaining the column of weekly supply of materials, the records of daily working, for a month or more, have in some cases been taken; while in others, it has been derived, by calculation, from the number and proportion of *charges*. Of the former, the Roaring Creek, Phœnixville and Columbia furnaces, (Nos. 3, 4 and 7,) are examples. It is to be hoped that, after a more prolonged action shall have brought each of these establishments to a uniform rate of working, we shall be able to substitute, for the numbers here given, such as shall require no deductions on account of the occasional daily variations in the coming down of charges.

The following is a tabular view of the blast furnaces, applied to the manufacture of iron with the anthracite of Pennsylvania.

## TABLE I.

| No. of Furnace. | Name and situation of Furnace. | Name of Proprietor. | Name of Occupant. | When built. | Date of commencing Blast with anthracite. | Dimensions of Stack in feet. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Side of the base. | Height. | Diam. of Boshes. | Square of the Hearth. |
| | | | | | | feet. | feet. | feet. | feet. |
| 1 | Mauch-Chunk. | Baughman, Guiteau, & Co. | The Owners | 1838.... | Aug. 27, 1838. | 22 | 21½ | 5½ | $1\frac{5}{12}$.. |
| 2 | Pottsville.... | Marshall, Kellogg, & Co. | Ditto ....... | 1838.... | July 10, 1839. | 30 | 35 | 8¾ | 3½... |
| 3 | Roaring Creek. | Burd Patterson, & Co. | Dr. Steinberger. | 1838–9.. | May 18, 1840. | 30 | 30 | 8½ | ...... |
| 4 | Phœnixville. | Messrs. Reeves.... | The Owners | 1837.... | June 17, 1840. | 28 | 33 | 8 | 3 by 6½ |
| 5 | Danville.... | Biddle, Chambers, & Co. | Ditto ....... | 1838–9.. | April, 1840 | 30 | 30 | 7½ | ...... |
| 6 | Crane Iron Works, near Allentown. | Crane Iron Co. | Ditto........ | 1839–40. | July 4, 1840. | 30 | 40 | 12 | 3½... |
| 7 | Columbia at Danville. | George Patterson | Messrs. J.P. & J. Groves. | 1839.... | July 2 1840. | 30 | 33 | 8½ | 3½... |
| 8 | Montour at Danville No. 1. | Biddle, Chambers, & Co. | The Owners | 1840.... | July 11, 1841. | 37 | 32 | 12 | 4.... |
| 9 | Ditto, No. 2. | Ditto .............. | Ditto ....... | 1840.... | August, 1841. | 37 | 32 | 12 | 4.... |
| 10 | Shamokin .. | Shamokin Iron Co. | Ditto ....... | 1840...... | ........ | 40 | 42½ | 12 | 4.... |
| 11<br>12<br>13<br>14 | Stanhope, N. J. | Stanhope Iron Co. | Ditto ....... | 1840–1.. | April 5, 1841. | 30 | 30 | 10 | 3½... |

| Materials and yield per week, in tons. | | | | Number and proportion of charges in 24 hours. | | | | Air supplied to the Furnace. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ore. | Anthracite | Limestone | Pig metal produced. | Number of charges. | Ore. | Anthracite | Limestone | Cubic feet pr. minute | Pressure in lbs. per sq. inch. | Tempera-ture, Fahr. | Weight of air per ton of pig. | Number of tuyeres used. |
| | | | | | lbs. | lbs. | lbs. | | | degs. | tons. | |
| ...... | ...... | ...... | 8... | ...... | ...... | ...... | ...... | ..700. | ..2... | ..450. | ..21.6 | ..2 |
| 68.7. | 31.2. | 31.2. | 28. | ..20.. | 100 scrap iron and 1100 ore | 500. | ..500. | ·3769. | ..1.5. | ..600. | ...... | ..3 |
| 84... | 56... | 21... | 40... | ..28.. | 960.. | ..600. | ..254. | .2400. | ..2.5. | ..650. | ..20⅓. | ..3 |
| 73... | 59... | 24.1. | 28... | ..31½. | 740.. | ..600. | ..245. | .1732. | ..1.5. | ..700. | ..20.8 | ..3 |
| 70.3. | 46.8. | 35... | 35... | ..25.. | 900.. | ..700. | ..448. | .2414. | ..2.75 | ..600. | ..23.2 | ..2 |
| 104... | 69.3. | 52... | 50... | ..66.. | 504.. | ..336. | ..252. | .5065. | ..2.5. | ..600. | ..34.. | ..3 |
| 93.4. | 81.3. | 64.15 | 31.5. | ..28.. | 1200.. | .1050. | ..800. | .1861. | ..3... | ..612. | ..20.4 | ..3 |
| 154... | 108... | 61.6. | 70... | ..44.. | 1120.. | ..784. | ..448. | .5026. | ..4... | ..612. | ..24.8 | ..3 |
| ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ..3 |
| ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ..3 |
| 112.6. | 80.9. | 34.68 | 56... | ..37.. | .975.. | ..700. | ..300. | .4071. | ..3... | ..600. | ..25.. | ..3 |

## TABLE I.

| No. of Furnace. | Name and situation of Furnace. | Blowing Machinery. | | | | Water power employed. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of blowing cylinders. | Diameter of cylinders. | Length of stroke. | Number of strokes per minute. | Height of wheel. | Length of buckets. | Depth of buckets. | Revolutions per minute. | Head and fall in feet. | Horse powers of wheel. |
| | | | inches | inches | | feet. | feet. | inches | | | |
| 1 | Mauch-Chunk. | .2.. | ..72.. | ..11.. | .13½.. | .14... | ..3½.. | ..8... | .13½.. | .17. | ...... |
| 2 | Pottsville... | .2.. | ..40.. | ..72.. | .18... | ...... | ...... | ...... | ...... | .... | ...... |
| 3 | Roaring Creek. | .2.. | ..44.. | . 60.. | .11.4. | .20... | ..8... | .12... | ..5.7. | .21. | .29.4. |
| 4 | Phœnixville. | .2.. | ..42.. | ..48.. | .11.25 | .12.25 | ..8... | .10... | .11¼.. | .14. | .15.1 |
| 5 | Danville.... | ...2.. | ..40.. | ..42.. | .20... | ...... | ...... | ...... | ...... | .... | ...... |
| 6 | Crane Iron Works, near Allentown. | .2.. | ..60.. | ..72.. | .10.75 | .12... | .25... | .21... | ..3⅔.. | ..8. | .64.5. |
| 7 | Columbia at Danville. | .2.. | ..32.. | ..64.. | .15⅝.. | ...... | ...... | ...... | ...... | .... | ...... |
| 8 | Montour at Danville, No. 1. | .4.. | ..40.. | ..72.. | .16... | ...... | ...... | ...... | ...... | .... | ...... |
| 9 | Ditto, No. 2. | .4.. | ..40.. | ..72.. | ...... | ...... | ...... | ...... | ...... | .... | ...... |
| 10 | Shamokin .. | ...2.. | ..62.. | ..72.. | ...... | ...... | ...... | ...... | ...... | .... | ...... |
| 11<br>12<br>13<br>14 | Stanhope, N. J. | .2.. | ..72.. | ..72.. | ...13. | .20... | ..8... | ...... | .21¼.. | .... | ...... |

CONTINUED.

| Steam power employed. | | | | | | | | Subsidiary Fuel. | | Nature of ores used. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diameter of steam cylinder. | Length of stroke. | Revolutions per minute. | Number of boilers. | Length of boilers. | Diameter of boilers. | Pressure of steam pr. sq. in. | Estimated horse power. | For steam power per day. | For heating blast, per ton of pig. | Locality and character. | Yield per cent. |
| inches | feet. | | | feet. | inch | lbs. | | tons. | cwt. | | |
| ...... | .... | ...... | .... | .... | .... | ...... | ...... | ...... | ...... | Hematite and magnetic of N. J. | 40 to 70 |
| ..15.. | .6.. | ..18.. | .8.. | .20. | .30. | .125.. | ..80.. | ...... | ...... | Carbonate and hematite. | 25 to 50 |
| ...... | .... | ...... | .... | .... | .... | ...... | ...... | ...... | ...4.. | Fossiliferous peroxide of Bloomsburg. | 50 to 64 |
| ...... | .... | ...... | .... | .... | .... | ...... | ...... | ...... | ........ | Hydrated peroxide.... | 38 to 50 |
| ..12.. | .4.. | ..30.. | .4.. | ·20. | .30. | .100.. | ..40.. | ..4... | ...4.. | Calcareous peroxide of Danville. | 45 to 60 |
| ...... | .... | ...... | .... | .... | .... | ...... | ...... | ...... | ...5.. | Hydrated peroxide near the works. | 40 to 55 |
| ..12.. | .3½. | ..25.. | .4.. | .20. | .30. | .100.. | ..40.. | ..3½.. | ...5.. | Calcareous, fossiliferous peroxide. | 45 to 60 |
| ..24.. | .6.. | ..16.. | .8.. | .20. | .30. | ..60.. | ..90.. | ...... | ...5.. | Fossil calcareous, & silicious peroxide. | 33 to 60 |
| ..24.. | ·6.. | ..20.. | .8.. | .20. | .30. | ..60.. | ..90.. | ...... | ........ | ......... Ditto. ......... | 33 to 60 |
| ..22.. | .6.. | ...... | 10.. | .30. | .30. | ..70.. | .160.. | ...... | ...... | Carbonate & Danville fossiliferous. | 33 to 60 |
| ...... | .... | ...... | .... | .... | .... | ...... | ...... | ...... | ...4½. | Magnetic of Irondale. | 50 to 70 |

## *Remarks on the preceding Table.*

### 1. MAUCH CHUNK FURNACE.

The furnace at Mauch Chunk, which stands at the head of the preceding table, is believed to have been the first in this country, at which any considerable success was attained in the smelting of iron with anthracite.* The iron

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* Mr. Crane's patent in this country, bears date November 29, 1838. The Mauch Chunk furnace went into blast for the *second time*, about the same day. The operations at Pottsville were commenced July 10, 1839. But the trial of three months' continuance, began about the 20th of October, 1839, and its completion was celebrated on the 18th of January, 1840. The blast of 100 days, *terminated* at Mauch Chunk, November 2d, 1839. The following letter shows the period at which Messrs. Baughman, Guiteau & Co. commenced their works — with other particulars worthy of notice.

*Beaver Meadow, November* 9, 1840.

SIR,

Agreeable to a request of Col. Henry High, of Reading, I send you the following hastily written statement of the experiments made by Boughman, Guitean & Co., produced was of various, but mostly inferior qualities, owing probably to a deficiency of

in the smelting of iron ore, with anthracite coal as a fuel.

During the fall and winter of the year 1837, Messrs. Joseph Baughman, Julius Guiteau, and Henry High, of Reading, made their first experiment in smelting iron ore with anthracite coal, in an old furnace at Mauch Chunk, temporarily fitted up for the purpose; they used about eighty per cent. of anthracite, and the result was such as to surprise those who witnessed it (for it was considered as an impossibility even by iron masters); and to encourage the persons engaged in it, to go on. In order, therefore, to test the matter more thoroughly, they built a furnace on a small scale, near the Mauch Chunk Weigh Lock, which was completed during the month of July, 1838.

### *Dimensions.*

Stack, 21 1-2 feet high, 22 feet square at the base.

Boshes, 5 1-2 feet across.

Hearth, 14 by 16 inches in the square, and 4 feet 9 inches from the dam stone to the back.

Blowing apparatus consisted of two cylinders, each 6 feet diameter; a receiver, same diameter, and about 2 1-2 feet deep; stroke, 11 inches. Each piston making from 12 to 15 strokes per minute.

blast. The blowing cylinders are of wood, (single acting) and at the speed employed did

An overshot water wheel, diameter 14 feet; length of bucket 3 1-2 feet; number of buckets, 36; revolutions per minute, from 12 to 15.

The blast was applied August 27th, and the furnace kept in blast until September 10th, when they were obliged to stop in consequence of the apparatus for heating the blast proving to be too temporary. Several tons of iron were produced of Nos. 2 and 3 quality. I do not recollect the proportion of anthracite used. Temperature of the blast did not exceed 200° Fahrenheit.

A new and good apparatus for heating the blast was next procured, (it was at this time I became a partner in the firm of B., G. & Co.) consisting of 200 feet in length, of cast iron pipes, 1 1-2 inches thick; it was placed in a brick chamber, at the trunnel head, and heated by a flame issuing thence.

The blast was again applied about the last of November, 1838, and the furnace worked remarkably well for five weeks, exclusively with anthracite coal; we were obliged, however, for want of ore, to blow out on the 12th of January, 1839. During this experiment, our doors were open to the public, and we were watched very closely both day and night, for men could hardly believe what they saw with their own eyes, so incredunot furnish over 700 cubic feet of air per minute. Their apparatus for hot blast was at first

lous was the public in regard to the matter at that time; some iron masters expressed themselves astonished, that a furnace *could work* whilst using unburnt, unwashed, frozen ore, such as was put into our furnace.

The amount of iron produced, was about 1 1-2 tons per day, when working best, of Nos. 1, 2, and 3 quality.

The average temperature of the blast was 400° Fahrenheit.

The following season we enlarged the hearth to 19 by 21 inches, and 5 feet 3 inches from the dam stone to the back of hearth; and on July 26th, the furnace was again put in blast, and continued in blast until November 2d, 1839, a few days after the dissolution of our firm, when it was blown out in good order. For about three months we used no other fuel than anthracite, and produced about 100 tons of iron, of good Nos. 1, 2, and 3 quality. When working best, the furnace produced about 2 tons per day. Temperature of the blast was from 400° to 600° Fahrenheit. The following ores were used by us, viz. "Pipe ore," from Miller's mine, a few miles from Allentown; "brown hematite," commonly called *top mine*, or surface ore; "rock ore," from Dickerson's mine in New Jersey; and "Williams township ore," in Northampton county. The last mendefective, and was afterwards placed at the trunnel head, where it could not be so well

tioned ore produced a very strong iron, and most beautiful cinder.

The above experiments were prosecuted under the most discouraging circumstances, and if we gain any thing by it, it can only be the credit of acting the part of pioneers in a praiseworthy undertaking.

Most respectfully, Sir,
Your obedient servant,
F. C. Lowthorp.

Prof. Walter R. Johnson, Philadelphia.

It is proper to mention that the first account which reached this country relative to the operations of Mr. Crane, in manufacturing iron with anthracite in Wales, was in the proceedings of the Liverpool meeting of the British Association, for the year 1837. That meeting was held in September of that year, and the statement contained in the 6th volume of the proceedings of that body, page 52, (transactions of sections) is, that his operations were commenced with hot air, on the 7th of Feb., 1837. The following extracts are perhaps sufficient to convey a knowledge of the most important results then obtained.

" One of the three furnaces at present on the establishment, is a small cupola furnace, built from the top regulated as if arranged in separate ovens, with an independent fire. Hence, even of

of the hearth with fire bricks only. This cupola is of the following dimensions; 41 feet in its whole height, 10 1-2 feet across the boshes, and the walls of the thickness of two nine-inch bricks; the hearth 3 feet 6 inches square and 5 feet deep." "I have produced, from the cupola furnace, the ton of iron in the smelting process, on the average of three months, with less than 27 cwt. of anthracite coal; the heating of the blast and the calcination of the mine, require, of course, upon my plan, the same quantity of fuel which is necessary for the like processes in other establishments." "Since I have adopted the use of anthracite coal, combined with hot air, the produce of the furnace, with a pressure of 1 1-4 pounds per square inch, has ranged from 30 to 34 and 36 tons." "Its present weekly average may be expected to range from 35 to 36 tons." "With respect to the quality of the iron produced by the combination of hot blast and anthracite, the result is very satisfactory. It is well known that my cold blast iron, for all purposes where great strength was required, was never deemed inferior to any smelted in South Wales. That which I have hitherto produced with hot blast and anthracite coal, is, however, decidedly stronger than any other before smelted at the Yngscedwin iron works."

the limited supply of air taken into the bellows, a considerable portion must have been lost by leakage, and by escapes at the open tuyeres then applied.

## 2. Pottsville Furnace.

The Pottsville furnace is the same with which Mr. William Lyman made his experiments, which commenced at the date mentioned in the table. The continuous blast of three months, required by the conditions under which he received this furnace property, was completed in January, 1840. Since that period several occurrences have conspired to disturb the regularity of action in this establishment. At one time an attempt was made to heat the air in close furnaces, throwing it, in part, *through*, and in part *over*, the fire, which heated the blast, and thus sending in the *gaseous products of combustion*, as well as atmospheric air, to supply the furnace. This attempt failed, either because carbonic acid, nitrogen and sulphurous acid gas interfered too much with the combustion of the oxygen in that portion of air which had escaped the action of the heating fire, or because the cases or furnaces in which the air-heating fires were contained, proved inadequate to sustain the pressure, and thus supplied an insufficient quantity of the mixture to give a vigorous and powerful reducing heat at a proper height above the hearth.

This apparatus was used but for a short time, and when blown out, to re-establish the semicircular-tübe system, the hearth was found greatly enlarged, as might have been inferred from the black, heavy, though porous cinder which was the only kind obtained during the time this apparatus was in use. In fact, it appears that the unreduced oxide of iron came down and served as a flux to the hearth stone; a result which I have often known to occur where a deficient blast allowed any considerable portion of the ore to escape reduction. Pure pig metal, when fairly collected in the hearth, has no action on good fire-stone or fire-brick, any more than has the well-reduced vitreous cinder, which ought to accompany the production of good foundry iron.

Besides the difficulties attending the air-heating apparatus, which has again given way, the Pottsville furnace has been supplied with ores of almost every variety, mixed, or used separately without proper discrimination, and sometimes, it is alleged, the stock has become nearly or quite exhausted, leaving the works to go on without any addition of ore for hours together. It is not surprising that, under these circumstances, iron of very different qualities should be produced, and that this furnace should, with all its advantages of being situated amidst the greatest abundance of anthracite, be able to render a less satisfactory result of the anthracite iron manufacture than those which have fewer apparent advantages.*

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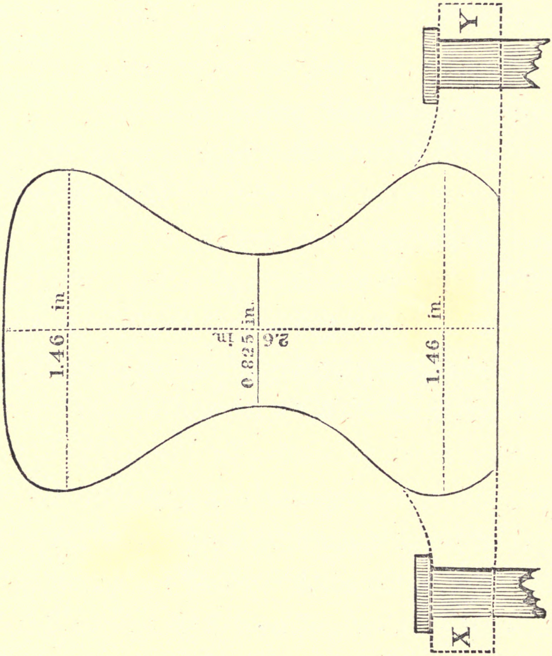
* A second furnace near Pottsville, called the Valley Furnace, was put into blast September 17, 1841, and is represented to have succeeded admirably from the first moment of its action. It uses only the ore found upon the ground in connexion with the anthracite beds.

The iron recently made at Pottsville has been cast from a cupola either into T rails, for mine roads, or into cannon balls for the government. That it is of good quality for the former purpose I had an opportunity, through the kindness of the proprietor, of testing by actual experiment. A rail was taken at random from a large pile, recently cast, and subjected to the following test:

The rail was 6 feet long, and had the form of cross section, represented in the annexed figure, containing in its area 3.1 square inches. It had at each end, for about 3 inches, along the base, wings or flanges for securing it to the cross-ties, as represented by the dotted lines X and Y, and in the middle of its length similar wings, 6 inches long, or 3 inches on each side of the centre. The rail weighed 66 lbs., or 33 lbs. per yard. To prove its flexibility and strength, its two extremities were placed on supports 5 feet 9 inches apart, and of such height as to allow of the suspension of weights beneath the centre of the bar. A strong stirrup was passed over the rail, before placing the latter on its supports, and carried to the centre. To this, the chains supporting the



weights were attached. A straight-edged, broad ruler was adjusted beneath the rail, from which the deflections could be easily measured.

The following weights were then added and observations made: —

1. With 320 lbs. (including, of course, the chains and stirrup,) a deflection of 0.02 inch.
2. With 1040 lbs. “ 0.20 “
3. “ 2000 “ “ 0.37 “
4. “ 2525 “ “ 0.50 “
5. “ 3000 “ broke.

This last weight was sustained about 4 minutes before the rail gave way.

The fracture took place just outside of the wing already mentioned, and, of course, 3 inches from the centre. Hence the strengthening effect of the wing was proved, and led me to recommend a pattern, in which the wings should extend the whole length of the rail.

Another rail, intended to sustain locomotives, made of the same iron, and on a pattern entirely *similar* to the first, was also partially tested, but not broken.

It had the following dimensions, viz.

Length, 6 feet;
Depth, 4 inches;
Breadth at top, 2.5 inches;
Do. at bottom, 2.5 “
Do. of mid-rib, 1.25 “

Weight, 134 lbs., or 67 lbs. per yard; consequently its area of cross section was almost exactly double that of the first rail.

This rail having been placed on the two supports, at the same distance apart as in the first trial, weights were applied and deflections observed as follows, viz.

| | | | | | |
|---|---|---|---|---|---|
| 1000 | lbs. | produced a | deflection of | 0.08 | inch. |
| 2000 | “ | “ | “ | 0.15 | “ |
| 3000 | “ | “ | “ | 0.20 | “ |
| 4000 | “ | “ | “ | 0.26 | “ |
| 4500 | “ | “ | “ | 0.28 | “ |

After this weight had been applied, the arrangement of props to preserve the supports erect gave way, and time not allowing a repetition of the trials, they were given over for the present, having, as was believed, satisfactorily proved that a rail made of this iron, of the dimensions above tested, would, when supported both at the ends and centre, be adequate to sustain the weight of any locomotive now in use. The strength, when supported in the middle as well as at the ends, being double of what it is when supported at the ends alone, if we take the strength of the first rail as a standard, and compare the *breadths and squares of the depths* of the two cross sections together, we shall find, that, so far from having reached the ultimate strength of the large rail, with a weight of 4500 lbs. on a length of 69 inches, the latter would have required 12,158 lbs. to break it. Placed on cross ties 3 feet apart, the larger rail ought to bear about 12 tons as its ultimate load.

### 3. Roaring Creek Furnace.

The Roaring Creek Furnace stands about one fourth of a mile up the creek, above its mouth, which is in the north branch of the Susquehannah, three miles below the town of Catawissa, and five miles above Danville.

The reason of selecting this position, was in order to take advantage of the valuable water power of this stream, which, in the course of a mile or a little more, has a fall of not less than fifty feet. It is, however, not altogether free from objection, on account of the occasional failure of water in dry seasons.

The ore is the rich fossiliferous kind, from the neighborhood of Bloomsburg, distant about six or seven miles, and the limestone is also brought from the north side of the river, a distance of two or three miles. The coal is from Wilkesbarre, distant about forty miles, by the line of the North Branch canal. The water wheel appears to me to fulfil its purpose but imperfectly, and the machinery to move with considerable irregularity, owing in part to the want of counterpoises to the cranks and connecting rods of the blowing cylinders, which are laid horizontally; thus adding half the weight of the two long connecting rods and that of the two heavy cast iron cranks, to the regular resistance of the air in the cylinders, and by so much increasing for the moment the quantity of work to be done by the water wheel; and on the opposite part of the revolutions, the contrary effect takes place, to an extent which becomes very sensible in the movements of machinery, as well as in the intensity of the blast. The heating of the blast is effected on the plan of the Calder works.

The volume and pressure of air for this furnace, given in the table, was derived from the statement of the occupant, as that used in ordinary times; but at the period of my visit, September 12, 1840, the lowness of the stream caused a considerable reduction of volume, being then only 1672 cubic feet per minute, under a pressure of 1.332 pounds per square inch. The yield was then but 35 tons per week, and diminishing.

The pig metal made at the Roaring Creek Furnace is of excellent quality, being generally grey No. 1, and exceedingly well suited to foundry purposes. It has also been fully proved in regard to its adaptation to the purposes of making bar iron, by the Messrs. Whitaker, at Reading, who have, it is said, offered strong testimony in its favor.

By urging the furnace to its utmost with burthen, there was obtained for a few days a yield equal to 72 tons per week; but the metal was, of course, inferior in quality to the ordinary product.

The cost of this establishment, independent of the site, was $31,000.

### 4. PHŒNIX FURNACE.

The furnace at Phœnixville, situated twenty-five miles from Philadelphia, directly on the line of the Schuylkill navigation, is supplied with anthracite from Pottsville, and with ore from Yellow Springs, which contains a large portion of silica. The pig metal is grey No. 2, moderately soft, but wants toughness. Bar iron, manufactured from the pig of Phœnixville, is generally cold short. The burning out of hot air pipes and the destruction of hearth-stones, consequent, as is believed, on a deficient blast, have been frequent causes of embarrassment at these works. The ore yields 38.3 per cent., and about 1 3-4 tons of coal are required to make one ton of pig metal. The cost of building Phœnixville furnace, independent of wheel house and dwellings, was $7949. This includes cast and bridge houses.

## 5. Danville Furnace.

The Danville works use anthracite from Wilkesbarre, received by the North Branch canal, and ore obtained within half a mile of the furnace. Two or three varieties of the latter are found within a short distance of each other. The calcareous fossiliferous ore of Montour's ridge, yielding from 55 to 64 per cent. of metallic iron, is the chief reliance of the works; but large portions of the hard siliceous band ore, mined immediately in the neighborhood, is also extensively used. Both the soft and hard beds probably underlie the site of the works. The pig metal is of a dark grey color, granular texture, soft and fusible, well adapted for foundry purposes; and represented to be in no respect inferior to the best Scotch pig. The same remarks will apply to the products of furnaces Nos. 7 and 8.

The pressure of blast in this furnace is measured and regulated by a safety valve, loaded directly with weights to the amount of 2 3-4 pounds per square inch, and under this load the air constantly escaped in moderate quantity at the time of my visit.

### 6. Crane Furnace.—No. 1.

The Crane Iron works have been erected under the immediate direction of Mr. David Thomas, who had been previously engaged at the establishment of Mr. Crane, in Wales. They are situated about three miles from Allentown, on the line of the Lehigh navigation. The volume of air passing through the bellows, is the quantity given in the table, computed from the known length of stroke and diameter of piston, together with the observed number of strokes per minute, and it is this volume, assumed to be under the pressure also noted in the table, which I was assured by Mr. Thomas, was the load on the safety valve when examining the works. A considerable quantity of air was escaping at the safety valve, and a part is used to supply the heating ovens for hot blast, as is also done at Roaring Creek and elsewhere. Of the economy of this latter arrangement, except where very fine coal is used for heating, I am disposed strongly to doubt. A single high chimney, with suitable register, to regulate the draught, might, I apprehend, be entirely equivalent, and being self-acting, would require no constant expense of power to maintain the combustion. The water wheel was intended to supply two furnaces.

The *stock* at this furnace is very expeditiously elevated from the level of the base of the stack, by means of water pumped up by the blast wheel, into a cistern near the trunnel head, and which is thence allowed to flow alternately into two boxes of suitable dimensions, suspended by a chain passing over a pulley in such a manner, that the descent of one box filled with water, and bearing on its cover the empty barrows for stock, elevates the other box now emptied of water, but carrying up the barrows, loaded with ore, coal, and limestone.

The blast in this establishment is heated in four ovens, each having twelve arched tubes of five inches interior diameter, and two inches thickness of cast iron. The temperature, when tried in my presence, was not sufficient to melt lead, though it was understood to be, in general, capable of producing that effect.

The ore chiefly used at this furnace, is the hematite or hydrated peroxide of iron, of which about 2 1-2 tons are required to make 1 ton of pig metal. It is used entirely in its raw state. It was stated to cost at the works $2.25 per ton. The anthracite is from the mines of the Lehigh Coal Company, near Mauch Chunk, of which 87.5 per cent. is carbon, and 5.5 earthy matter. A quantity of the metal made at this furnace has been puddled with anthracite, at Boonton, New Jersey, and produced excellent fibrous bar iron. It was stated, that 21 cwt. of pig produced 20 cwt. of puddled iron, thus showing a loss in the first process of making bar iron of only 4.76 per cent. and that 22 1-2 cwt. made a ton of bars, showing altogether a loss of but 11.11 per cent. The foundation of a second furnace is prepared.

## 7. Columbia Furnace.

At the Columbia Furnace, in Danville, an attempt was at first made to heat the blast in a chamber above the trunnel head, but the pipes were soon burned away, and leaked to such a degree as to lose a large portion of the blast. The engine was, at the same time, too small and deficient in power. A succession of nozzles of different sizes, viz., 1 1-4, 1 1-2, 1 3-4, 2, and 2 1-2 inches in diameter, was tried. The greatest yield of iron during the first blast, which lasted only five weeks, was 5 tons in 24 hours, and during that time the 2-inch nozzle was employed. When, after this blast, the furnace was blown out, the hearth and inwalls were found very much cut away, the former being enlarged from 3 1-2 to 5 feet in diameter. The cinder, as usually happens when similar destruction is going on, was constantly black, and often highly porous.

The most successful operations were performed while the blast was most powerful, — the cinder and pig metal being then both superior to what they were at any other time. The same furnace manager, Mr. B. Perry, who had the care of the Pottsville furnace during its *prize blast* of ninety days' continuance, and who likewise blew in the Roaring Creek furnace, which succeeded from the first moment of its action, had charge of the Columbia furnace during the period above referred to; so that its want of immediate success cannot be attributed to inexperience; and as all the materials are essentially the same in kind as those used at Roaring Creek, we are compelled to believe that want of sufficient blast was the main cause of the little success which attended the first trial at this establishment.

The consumption of stock and yield of pig metal, recorded in the table, were taken from the records of the establishment for the month of May, 1841. It will be seen that the ore required per ton of pig was nearly 3.00 tons ;

| | | |
|---|---|---|
| Anthracite, - - - | 2.58 | " |
| Limestone, - - - | 2.03 | " |
| Air, - - - - | 20.4 | " |

On the 27th of July, 1841, the Columbia furnace was in active operation and making excellent grey foundry iron, and on that day I took the observations relative to the volume pressure and temperature of the blast, recorded in the table.

The large proportion of anthracite used to make a ton of pig, at these works, was accounted for by the proprietors, by stating that at the time to which these notes refer, they were using a considerable quantity of Shamokin coal, which they represented to be much inferior to that of Wilkesbarre, even alleging that two tons of the latter were, for all purposes at the furnace, equal to three of the former. The very large proportion of limestone will also appear singular to those who reflect that the ore itself is calcareous, being in part derived from that portion of the fossiliferous bed which has not been exposed to the decomposing influences of the air. The correctness of the judgment in regard to the anthracite of Shamokin, will no doubt be, ere long, put to a full test in the fine establishment No. 10, of the table, which is now nearly completed.

The force of engines computed from the quantity of air furnished and the pressure under which it is supplied, show that the power required at the Columbia is that of 29.7 horses.*

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* Thus air, *compressed* with 3 lbs. per square inch, is subjected to a total pressure of 18 lbs., or 1 1-5 atmospheres, or 6-5 atmosphere ; and its bulk will accordingly be 5-6 as great as when only under ordinary atmospheric pressure. The bulk of 1861 cubic feet, supplied by the machine in one minute, will become, when compressed, 1550 cubic feet. The compressing power expended, before any air escapes from the blowing cylinder, is very nearly one half as great as would be required to force out the 1-6 of air after compression, which occupied the space through which the piston moved before any began to escape through the valve. Hence the total mechanical force will be 11-12 of what would be re-

## 8 and 9. MONTOUR FURNACES.

These two furnaces having lately gone into blast, it is not practicable to deduce from their operations any very certain results, as the data relative to the charging, yield and operation of the works were obtained on the 27th of July, 1841, only sixteen days after the first was put into blast. The second, (No. 9,) is understood to have been since put into operation, and both to be performing well. The pig metal, obtained on the day when the establishment was visited, was good grey No. 1,

quired to expel the cylinder full if originally under the pressure of 6-5 of an atmosphere. Thus, 11-12 × 1861 = 1705 cubic feet, are to be put in motion under a pressure of 144 × 3 = 432 pounds per square foot; and 1705 × 432 = 736,560 pounds moved one foot or raised one foot high in a minute. Adding to this 1-3 for friction, and dividing by 33,000, (the pounds raised one foot high per minute, which represents a horse power,) we get

$$\frac{736{,}560 + 245{,}520}{33{,}000} = 29.7 \text{ horse power.}$$

and the cinder indicated an easy working. The coal used was partly from Wilkesbarre and partly from Shamokin, the latter having been but very recently employed, and its efficiency therefore not adequately tested.

These furnaces are admirably situated in regard to the ore, two valuable beds of which underlie the base of the stacks; and being on a great line of public works, have little to fear from the suspension of operations owing to want of means of transporting their coal. The plan adopted of using 4 blowing cylinders has, it appears to me, little to recommend it on the score of either economy or convenience. The blast used at a pressure of 4 lbs. to the square inch is also of questionable economy, involving a great loss at all the crevices and joints of the apparatus. The furnace which was in action at the period of my visit was certainly performing well, so far as the nature of the product was concerned. It should be mentioned that the proprietors of these works are erecting a large rolling-mill at Wilkesbarre, where they intend to puddle iron with anthracite.

## 10. Shamokin Furnace.

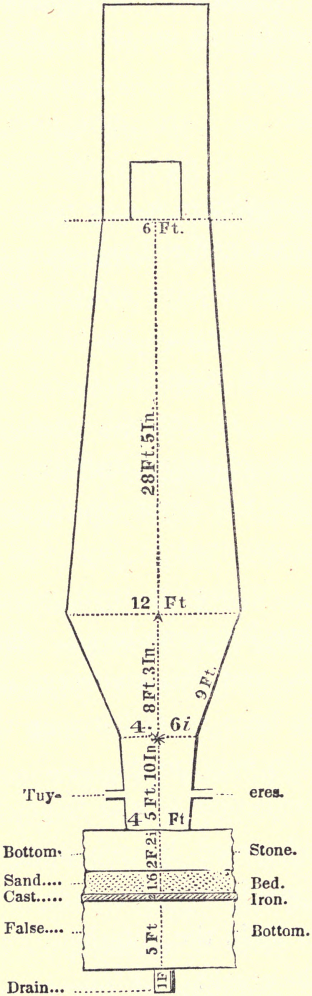
The Shamokin furnace can as yet furnish no data for judging of the efficacy of the arrangements there adopted, but by observing the ample provision for power, that of two high-pressure steam engines of 80 horse power each, having 10 boilers of 30 feet long and 30 inches in diameter, with steam cylinders 20 inches in diameter and 6 feet length of stroke, working under a pressure of 70 pounds to the square inch, it is evident that all which blowing machinery can do to insure success may be confidently expected in this establishment. The engines are the same which were put up and used at the coke furnace in Farrandsville, already referred to.

The air-heating apparatus consists of three heating ovens, with 15 Calder tubes to each, and four others with 20 tubes each, making 125 tubes in all. This apparatus for blowing and heating air is intended for two furnaces, of the dimensions recorded in the table. The coal will be brought to the furnace from mines but a few hundred yards distant, and the ore may be found within half a mile of the same point. Limestone was also observed within 30 or 40 rods of the stacks. It was originally intended to carry a rail-road to the trunnel head, but the elevation of the materials by machinery has more recently been decided on, and the road accordingly laid to the *base* of the furnace. A second furnace is in progress.

The works now under review will probably be found to solve completely the question of the profitable operation of anthracite establishments on a large scale, and in situations analogous to those of the great iron works of Britain. With regard to their steam machinery it may probably be found that something is yet to be done to economize heat. The The enormous waste by radiation, especially from steam pipes and cylinders, should be guarded against; and if the gas from the steam furnaces be found to escape into the chimney at too high a temperature, a more economical form of boiler should be adopted. The subsequent developments of this essay will be found to justify this opinion. A low pressure engine, to be worked by the escape steam of the two high pressure ones now built, may possibly be found no bad addition in connexion with a foundry or a new furnace.

As both grey and red ash coals are found at Shamokin, the relative values of the two in the blast furnace may be tested, as also the opinion, already referred to, of the value of Shamokin coal in general, as compared with the anthracite of other districts. This latter point may be the more readily settled inasmuch as the ore used at first will be that of Danville, in connexion with which this coal has heretofore been employed. Exchanges of coal for ore, and the contrary, ton for ton, have already been made between the Danville and Shamokin companies.

The construction of the Shamokin furnace will be understood by the annexed sketch, (page 62), exhibiting, on a scale of 10 feet to 3-4 of an inch, the interior form and foundation of the stack.


6 Ft.
28Ft.5In.
12 Ft
8Ft.3In.
9Ft.
4. 6i
5Ft.10In.
Tuy-
eres.
4 Ft
Bottom
Stone.
2F.2i
Sand....
Bed.
1.6
Cast.....
Iron.
2
False....
Bottom.
5 Ft
Drain...
1F

## 11, 12, 13, 14. STANHOPE FURNACES.

The works at Stanhope, Morris county, New Jersey, are, in some respects, the most interesting of all the anthracite iron furnaces in this country. They stand near the summit level of the Morris Canal, between Easton on the Delaware, and Newark on Raritan Bay. By this canal, the coal from Mauch Chunk, Beaver Meadow, Hazleton, Sugar Loaf, Buck Mountain and Summit Company's mines may arrive on the bank, at the level of the trunnel head of these furnaces. The waters of Rockaway river, with a fall of more than 50 feet, are used for the moving power, and the magnetic ore, found in such abundance in that part of New Jersey, is exclusively employed at this establishment. This last circumstance is what gives the highest interest to the Stanhope works. To reduce, in a blast furnace and without admixture of other ores, this rich mineral, by the aid of anthracite, is what others had hardly dared to hope. The complete success of the undertaking constitutes an era in the business, of which the Stanhope company may justly be proud; an era, perhaps, equally important to the two states which respectively furnish the ore and the anthracite.

The greatest amount of iron which had been made per day, previous to the 12th of June, 1841, when these works were visited, was 9.23 tons, or 64.61 tons per week, which was not however continued for many days in succession. On the 11th of June, the product was 14,644 lbs., and on the 12th, 14,630; or at the rate of 45.7 gross tons per week. A slight derangement of the conducting tubes had, it was said, caused a temporary falling off in the yield for two or three days. Fifty-six tons per week was stated to be the average product. The iron was not remarkable for toughness, though very soft, and probably a re-melting in the cupola would improve its quality as cast iron.

The variety of anthracite preferred to others at these works is that of Beaver Meadow. Coal has been delivered at the works at four or four and a half dollars per ton.

### 15. SCHUYLKILL VALLEY FURNACE.

This furnace has been put into blast since a part of the foregoing pages were sent to press, and it is not therefore practicable to do more than refer to casual statements which have reached us relative to the immediate success of its operations. Its situation is certainly not less favorable in regard to materials than that of the Pottsville or Shamokin furnaces. In reference to ore, it is probably as advantageously located as any others, except perhaps the Shamokin and Danville establishments.

### GENERAL COMPARISONS.

In order to compare the supply of air and the yield of iron, with the area of cross section of each furnace at the boshes, and the power employed, with the yield in pig metal per week, the following table has been constructed from the data furnished by the table at pages 28—31.

## TABLE II.

| Name of furnace. | Diameter of boshes. | Area of boshes in square feet. | Yield of pig metal per week. | Area of boshes, giving one ton of iron per week. | Air blown to each square ft. of bosh per minute. | Cubic feet of air furnished by the cylinders per minute. | Power required to inject the air into each furnace. |
|---|---|---|---|---|---|---|---|
| | Ft. | | Tons. | sq. ft. | cub.ft. | | h. p. |
| Mauch Chunk.. | 5½ | 23.750 | 8 | 2.968 | 29.47 | 700 | 7.66 |
| Pottsville........ | 8¾ | 60.130 | 28 | 2.147 | 62.68 | 3769 | 31.4 |
| Roaring Creek.. | 8½ | 56.745 | 40 | 1.418 | 42.29 | 2400 | 32.4 |
| | | | 35 | 1.625 | 28.94 | 1672 | 12.8 |
| Phœnixville..... | 8 | 50.265 | 28 | 1.795 | 34.45 | 1732 | 14.16 |
| Danviile......... | 7½ | 44.178 | 35 | 1.262 | 54.63 | 2114 | 35.6 |
| Columbia....... | 8½ | 56.745 | 31.5 | 1.801 | *32.79 | 1861* | 29.7* |
| Montour........ | 12 | 113.097 | 70 | 1.615 | 44.44 | 5026 | 104.6 |
| Cranework...... | 12 | 113.097 | 50 | 2.261 | 44.78 | 5065 | 68.3 |
| Stanhope........ | 10 | 78.540 | 45.7 | 1.718 | 51.83 | 4071 | 65.1 |

* On examining and comparing this result with others, there seems to be reason to suspect that some error has been made in either observing or noting the number of strokes of the pistons in the blowing and steam cylinders at the Columbia furnace. As recorded in table 1, the speed of the former is but 5-8ths that of the latter. It seems probable that this proportion should have been reversed. If so, the blowing cylinders will make 25 double strokes each per minute instead of 15 3-8ths. The bulk of air will then be 2977 cubic feet per minute instead of 1861, and the air per square foot of bosh, will be 52.49 cubic feet — more nearly corresponding with that of the Danville furnace, — and the power will be that of 47.5 horses.

The formula employed for computing the power required to inject the bulk of air given by observation, and under the pressure noted, is $.00576\ p\left(\frac{15\ A}{15+p}+\frac{A-\frac{15\ A}{15+p}}{2}\right)=$ the horse powers of the blowing machine, whether water or steam. Here A = the bulk of air in cubic feet per minute, and p = the pressure in pounds per square inch, within the blowing cylinders. The horse power is that of Watt, and the allowance for friction, &c. is supposed to be one fourth of the whole, or one third as much as is required to compress and inject the air.

The initial pressure of the air is assumed to be 15 pounds to the square inch, and the temperature 60°. It would be as yet a misplaced refinement to enter into minute computations relative to the quantity of moisture in the air, and the variations of force required in the machinery on this and similar accounts, at different seasons of the year. When with a limited power only at command, it is desired to inject an increased volume of air, the obvious expedient is to enlarge the area of the nozzles, and thereby reduce the *pressure* and increase the speed. When, at each stroke, a space is left above and below the pistons in the blowing cylinders, from which the air is not expelled, the recoil of this residual air after compression obviously causes it to occupy some portion of the space which would otherwise be filled by air newly admitted. Hence the importance of accurate adjustment between the piston and cylinder heads. The piston rods of blowing cylinders sometimes pass "through and through" both heads, especially when the cylinders are laid horizontally; and then the bulk of air taken in at each single stroke, is the same; but as this construction is not adopted at any of the anthracite works, a deduction is to be made of a few feet per minute for the bulk of the piston-rod filling a portion of the space on one side only at each revolution.

From the preceding table, it appears that great differences exist between the quantities of air required to be blown through a given section of boshes per minute; but that the average supply, including the two modes of driving Roaring Creek furnace, is 42.63* cubic feet of air to one square foot of bosh, but as this includes all the air blown, as well for heating ovens as for the furnace itself, the quantity taken by the latter will be considerably less. The iron made per minute by each square foot of boshes, is, on an average, 0.127 pounds, or 182 7-8 pounds in twenty four hours. Hence, the bulk of air required to pass the bellows in making 1 pound of iron, is 335 2-3 cubic feet, or 25 4-5 pounds.

With regard to the area of cross section at the boshes, as affecting the amount of iron made, it appears, that if we omit the Mauch Chunk furnace, and take Roaring Creek as making 40 tons per week, the production of one ton of pig iron per week, is derived from 1 3-4 square feet of bosh,—or one ton per day from every 12 1-4 square feet.

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* By the supposition in the preceding note, (page 66), this number will be raised to 45.13.

Comparing the whole number of tons produced per week, by all the furnaces with the whole amount of power by which the blast appears to have been furnished, we find 1.08* horse powers, as the force employed in giving one ton per week. If this result be increased to 1 1-4 horse power, it may, I think, be relied on as an entirely safe basis for calculations in the construction of blowing machinery for anthracite works, and give a surplus sufficient to answer in all emergencies.

The average force or pressure of blast, appears to have been 2.4 pounds per square inch, and though it has often been attempted to employ a blast greatly inferior to this in tension, I am not aware of much success having attended these attempts. Either a falling off in the yield, an inferiority of metal, or a destruction of the furnace hearth, has usually been the consequence. It is evident, that the amount of power required to inject the air will diminish in direct proportion to the decrease

* Or 1.13, in accordance with the note on page 66.

of pressure; but until some evidence more conclusive than what has hitherto transpired, shall be adduced in favor of a softer blast, it seems better to adhere to what is now giving good results in several of the anthracite furnaces.

## CHARACTER AND CONSTITUTION OF ANTHRACITE — AMOUNT OF BLAST REQUIRED FOR ITS COMBUSTION.

In the prosecution of the manufacture of iron, with any kind of fuel whatever, it is desirable to know in advance, at least within approximate limits, what amount of mechanical power will suffice to administer in the most advantageous manner, the requisite quantity of air to the furnace.

Two circumstances will chiefly determine this question.

*First,* the weight of oxygen required from the air, for the complete combustion of the fuel to be used in a given time.

*Secondly,* the pressure under which it is to be delivered to the furnace.

In the case of anthracite, the weight of oxygen will, in general, be easily computed, since it contains little or no other combustible than carbon, and since the quantity of this is pretty well ascertained, for the various coal fields which supply iron furnaces.

Analysis of single, well selected specimens of anthracite, must not, however, be too implicitly relied on. There is, inevitably, intermixed with the coal, more or less slaty matter, or coal of a semi-combustible character, which allows it to pass almost unchanged through the blast furnace. This, as well as the earthy residuum of the coal itself, is to be deducted, together with the volatile matter, before assigning the quantity of carbon which is to undergo combustion in the blast furnace. It will not be far from the truth to deduct for volatile matter, ashes and unconsumed coal or slate, 15 per cent. of all the anthracite which is put in at the trunnel head, leaving 85 per cent. for the carbon consumed. Some varieties will doubtless give a small per cent. more than this quantity, while others will yield less. To make the computation more nearly accurate, a large quantity of the particular anthracite used, should be analyzed, and the quantity of earthy matter, after incineration, be carefully weighed. If, in use in a furnace, the amount of unburnt slate and coal which comes through in a given time, should be ascertained.

The results obtained by calculations of the kind here indicated will of course give only approximations. The ore will furnish no inconsiderable quantity of oxygen. Some atmospheric air will escape combustion; and much of the gas escaping at the trunnel head is not carbonic acid, but carbonic oxide and carburetted hydrogen.

To aid in forming estimates of the volume of air required in anthracite furnaces, the following analyses of that material, from different parts of the coal regions, may be consulted.

Though not immediately connected with our present investigations, yet for the purpose of ready comparison, it has been deemed proper to add, in a subsequent table, some analyses of our free-burning bituminous coals.

## TABLE III.

*View of the composition of some of the anthracite coals of Pennsylvania, as determined by the writer's analyses.*

| Locality of Coal. | Sp. Gr. | Vol. Matter. | Carbon. | Ashes. |
|---|---|---|---|---|
| 1. Summit Co's Lands, head of Beaver Creek | 1.560 | 6.42 | 97.30 | 1.28 |
| 2. do. 2d bed | 1.594 | 4.31 | 91.69 | 4.00 |
| 3. do. 3d do | 1.613 | 7.51 | 87.48 | 5.01 |
| 4. do. 4th do | 1.630 | 9.60 | 85.34 | 5.06 |
| 5. Stevenson's Bluff, west of Beaver Meadow | 1.613 | 9.23 | 86.06 | 3.71 |
| 6. Buck Mountain | 1.559 | 5.90 | 91.02 | 3.08 |
| 7. Sugar Loaf Co., 1st specimen | 1.591 | 6.98 | 88.19 | 4.83 |
| 8. do. 2d bed | 1.574 | 5.36 | 85.91 | 8.73 |
| 9. do. same bed, but further down the slope | 1.550 | 6.87 | 90.71 | 2.42 |
| 10. Lyken's Valley, 1st sample | 1.391 | 7.60 | 87.95 | 4.45 |
| 11. do. 2d sample | 1.404 | 5.95 | 89.30 | 4.75 |
| 12. do. 3d do | 1.416 | 10.00 | 85.70 | 4.30 |
| 13. do. 4th do | 1.374 | 4.60 | 88.70 | 6.70 |
| 14. do. 5th do | 1.376 | 8 35 | 87.75 | 3.90 |
| 15. do. 6th do | 1.395 | 8.30 | 88.65 | 3.05 |
| 16. do. 7th do | 1.382 | 8.65 | 87.20 | 4.15 |
| 17. do. 8th do | 1.398 | 11.85 | 84.00 | 4.15 |
| 18. do. 9th do | 1.378 | 7.30 | 87.00 | 5.70 |
| 19. Mauch Chunk, Summit Mines | 1.590 | 7.90 | 87.10 | 5.00 |
| 20. Room Run Mines | 1.604 | 6.15 | 87.20 | 6.65 |
| 21. Pottsville | 1.569 | 6.71 | 86.54 | 6.75 |

The first nine of the above analyses, give a fair average of the coal at the eastern extremity of the middle coal field, and show that the volatile matter is 6.91, the fixed carbon 88.744, and the ashes, 4.346 per cent. The mean specific gravity of these nine varieties is 1.587. The second nine give the character of the north-western termination of the southern anthracite field. The mean per centage of volatile matter is here 8.066, of carbon 87.36, and of ashes 4.574.

The amount of these several ingredients in the last class of coals, is nearly identical with those of the anthracite used by Mr. Crane, in his iron works in South Wales.

## TABLE IV.

*View of some of the "free-burning" bituminous coals of Pennsylvania, suitable to be used in blast furnaces, either with or without coking.*

| Locality. | Sp. Gr. | Vol. Matter. | Carbon. | Ashes. |
|---|---|---|---|---|
| 1. Savage Mountain Coal trough Somerset County..... | 1.319 | 20.2 | 75.75 | 4.05 |
| 2. do. 2d bed........................... | 1.321 | 19.9 | 69.10 | 11.00 |
| 3. do. 3d do........................... | 1.343 | 21.8 | 69.90 | 8.10 |
| 4. do. 4th do........................... | 1.362 | 19.8 | 68.54 | 11.66 |
| 5. do. 5th do........................... | 1.363 | 18.3 | 71.50 | 10.20 |
| 6. do. 6th do........................... | 1.370 | 18.8 | 70.70 | 10.50 |
| 7. do. 7th do........................... | 1.386 | 20.1 | 68.46 | 11.44 |
| 8. do. 8th do........................... | 1.388 | 19.5 | 68.44 | 12.06 |
| 9. do. 9th do........................... | 1.480 | 18.7 | 68.56 | 12.79 |
| 10. do. 10th do........................ | 1.491 | 17.6 | 66.36 | 16.04 |
| 11. do. Maryland Mining Co. (Maryland.)............. | 1.437 | 15.62 | 68.56 | 15.82 |
| 12. do. George Creek, at Lonakoning, (Maryland.).......... | 1.346 | 16.03 | 70.75 | 13.22 |
| 13. Carbon Creek, Bradford Co. (Pa.) 1st sample........... | 1.515 | 15.00 | 62.60 | 22.40 |
| 14. do. 2d sample..................... | 1.448 | 17.40 | 70.00 | 12.60 |
| 15. do. 3d do.......................... | 1.465 | 19.10 | 63.90 | 17.00 |
| 16. do. 2d bed, 1st sample............ | 1.377 | 20.50 | 68.10 | 11.40 |
| 17. do. do. 2d do..................... | 1,378 | 19.20 | 65.50 | 15.30 |
| 18. do. do. 3d do..................... | 1.349 | 19.30 | 74.97 | 5.73 |
| 19. do. 3d bed, 1st sample............ | 1.388 | 17.90 | 69.00 | 13.10 |
| 20. do. do. 2d. do.................... | 1.400 | 18.90 | 68.57 | 12.53 |
| 21. Lick Run, Lycoming County, (Pa.) Diamond ply........ | 1.320 | 19.80 | 75.20 | 5.00 |
| 22. Quinn's Run, Lycoming County... | 1.372 | 18.80 | 74.40 | 6.80 |
| 23. Broad Top Mountain, Bedford Co. (Pennsylvania.)...... | 1.301 | 15.90 | 77.60 | 6.50 |

It appears from Table I. that the number of tons of anthracite supplied per week to seven furnaces, viz., Roaring Creek, Phœnixville, Danville, Crane, Columbia, Montour and Stanhope, is 501.3; and as these furnaces make 310.5 tons of pig metal per week, and demand, on an average, 4.5 cwt. of anthracite to each ton of pig for heating their blast, their total weekly consumption will be 571.16 tons. Hence the anthracite demanded for both smelting and heating blast is $\frac{571.16}{310.5} = 1.84$ tons = 1 ton 16 cwt. 3 qrs. 5.6 lbs. to the ton of pig metal produced. If this anthracite were pure carbon and were completely converted into carbonic acid, the weight of oxygen required for that purpose would be $\frac{16}{6} \times 1.84 = 4.906$ tons; but if we admit that the mean of the two sets of analyses above given represents the average quantity of carbon in Pennsylvania anthracite, viz., 88 per cent., then the quantity of oxygen will be but $\frac{88}{100} \times 4.906 = 4.317$ tons. As the oxygen is to be supplied from the atmosphere, of which the composition, (omitting moisture and impurities,) is 28 parts by weight of nitrogen to 8 of oxygen, the total quantity of *air* for one ton of pig will be $\frac{36}{8} \times 4.317 = 19{,}426$ tons; which, at 13.22 cubic feet to the pound avoirdupois, will be equal to 572,255 cubic feet. Hence it is easy to calculate what number of cubic feet of air should be delivered to the furnace and heating ovens, when we have determined how many tons of iron can be made per day. Thus, suppose the furnace to make 7 tons per day, the time for making one ton will be $1440 \div 7 = 205.7$ minutes, and the number of cubic feet of air *required to pass the nozzles* in one minute will be $\frac{572{,}255}{205.7} = 2782$.

The seven furnaces above named receive 22,569 cubic feet of air into their blowing cylinders per minute, and the aggregate area of their boshes is 512.67 square feet. The anthracite which they use will not probably yield over 85 per cent. of pure carbon, after deducting that which escapes combustion and comes out with the cinder, together with the slate unavoidably intermixed, and the dust which is projected out at the trunnel head. The quantity of anthracite which makes one ton of pig is, as above, 1.84 tons.

The *time* required for the seven furnaces to make one ton of pig is $\frac{17{,}640}{512.67} = 34.4$ minutes. The weight of carbon burnt in that time is $.85 \times 1.84 = 1.564$ tons; and this will require 2.66 times its weight of oxygen to form carbonic acid, or 4.16 tons. This quantity of oxygen will be contained in $\frac{36}{8} \times 4.16 = 18.72$ tons of air; which, at $29{,}612.^{8}$ cubic feet to the ton, gives $554{,}351.^{6}$ cubic feet of air to make one ton of pig; and as this takes 34.4 minutes, the air required to be burnt at all the furnaces per minute, is $554{,}351.^{6} \div 34.4 = 16{,}149$ cubic feet. Deducting this from 22,569, the quantity derived from observations on the movements of the blowing pistons,* we have a surplus of 6,454 cubic feet, or 28.4 per cent. of the whole, either not completely expelled through the eduction valves, or allowed to escape at the safety valves, joints and tuyeres, or remaining unburnt in the furnace and

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* See note, p. 66.

heating ovens. With regard to the latter, it may be safely asserted that they do not consume more than one half of the oxygen which passes through their grates.

In general, according to a preceding deduction, let the number of tons of iron which a furnace can make per day be represented by $\frac{B}{12.25}$; $B$ being the area of cross section of such furnace at the boshes. Then will the time, in minutes, of making one ton be $\frac{12.25}{B} \times 1440 = \frac{17640}{B}$. Let the proportion of carbon in 100 parts of the anthracite used be $\frac{c}{100}$, and the weight of anthracite, in tons, required to smelt one ton of pig be $a$; then the quantity of *carbon* consumed in making a ton of iron will be $\frac{ca}{100}$, and the weight of *air*, in tons, required for its combustion into carbonic acid, $\frac{16}{6} \times \frac{36}{8} \times \frac{ca}{100} = 0.12ca$. The conversion of this expression of the *weight* of air into *cubic feet*, is easily effected, since 13.22 cubic feet weigh one pound avoirdupois, and the ton of air consequently contains $2240 \times 13.22 = 29{,}612.^{8}$ cubic feet. Hence the number of cubic feet of air used in making a ton of pig metal will be represented by $29{,}612.^{8} \times 0.12ca = 3553.5ca$. Dividing this bulk of air by the above expression, representing the time in minutes required to make one ton of pig, we get $\frac{\frac{3553.5ca}{17640}}{B} = .2014caB =$ the number of cubic feet of air required per minute by the furnace and heating ovens. In other words, *multiply together the area of boshes in square feet,—the weight of anthracite in tons used per ton of pig, produced,—the number representing the per centage of carbon in the anthracite and the decimal* 0.2014, *and the product will give the number of cubic feet of air, before compression, which must enter the furnace and heating ovens per minute.* If we take into account the quantity of oxygen contained in the ore, it might be supposed that a large deduction would be allowable from the bulk of air given by this formula; but the quantity of oxygen which does not undergo combustion will account for the fact, that even a greater quantity than that given by calculation is actually injected into the fires.

It will of course be understood, that all the above deductions are to be regarded as approximations only, such as the present working of the several establishments enables us to make. To give exact data for calculations of this nature, they ought to be furnished with more correct instruments for observing and recording the several items which enter into the computation. The waste space above and below the piston should be known. The number of movements of piston per day should be marked by a self-registering apparatus; the pressure should be marked by an inverted syphon guage of large-sized glass tube; the two limbs being accurately of the same diameter, and connected at bottom by a section of diminished and almost capillary size, thus preventing rapid and violent oscillations, which always interfere with accurate experiments. Where works are situated at considerable elevations, the mean barometric pressure should be known, — and if the season of making observations do not extend through the year, the temperature and dew point of the air at the times of observing, should be reduced to that of the annual mean. It would be desirable to know, in all cases, the quantity of matter volatile at a white heat, both in the ore, the coal, and the limestone; as well as the fixed matter, other than iron, in the ore, the ashes of the coal, and the lime or other materials after calcination, in the limestone. The weight of cinder as well as of pig metal, which is drawn from the furnace, should be ascertained, if we would form a just and intelligent estimate of what is going on within. Due economy of moving power, is every where more or less important, and hence the accuracy of workmanship in blowing apparatus, can hardly be over-estimated. Where anthracite is transported to a distance for supplying this force, the best means of applying its heating power should be well understood. Great economy has within a few years been obtained by an attention to philosophical principles, in generating and using steam, whether obtained from wood or from mineral fuel; and since the most wasteful practices often exist in connexion with this part of an iron establishment, a careful attention should be given to ascertain the quantity of water by weight which goes into the boiler, per week, as well as its temperature and the weight and quality of the anthracite with which the evaporation is effected. The evaporative power of anthracite, that is, the number of pounds of water which can be vaporized by the combustion of one pound of the fuel, has already engaged attention, and is likely to be still more minutely examined. Among the causes which interfere with the economical action of steam boilers, is the want of sufficient heating surface in the boiler, compared with the quantity of steam which it is required to supply, and the consequent necessity of urging the draught to such a degree as to carry away a great portion of heat in the gases which escape into the chimney. The use of high pressure steam, without condensation, of course involves the loss of at least one atmosphere in the total pressure generated. So important is the subject of the heating and evaporating power of anthracite to the iron master, as well as to the manufacturer and to the navigator by steam, that no apology, will be required by the reader for our introducing the following remarks in relation to this subject.

## Evaporative Power of Anthracite.

Writers have heretofore stated, that when bituminous coal is submitted in gas retorts or coking ovens, to such a temperature as to deprive it of a large portion, or the whole of its volatile matter, it still retains nearly the same heating power in the form of coke, which it had possessed in that of coal.

Thus, in his paper on the evaporative power of coal, in the transactions of the Institution for Civil Engineers, Vol. 2, p. 159, Mr. Josiah Parkes, says, "I have myself invariably found, as might be expected, that species of coal to be the strongest fuel, which contained the least gas, and *vice versa.*"

"I have also found that 75 pounds of coke produced from 100 pounds of coal, evaporated as much water as 100 pounds of the self-same coal."

When burning coal yielding 34 per cent. of volatile matter, Smeaton found that its coke would produce, on the same grate, 83 1-3 per cent. as much effect as an equal weight of the coal; but it is probable that had the grate been adapted to coke, the effect of the latter might have been still more favorable.

Mr. Apsley Pellatt's experience, in a glass furnace is cited by Mr. Parkes, as follows: "Mr. Pellatt's mode of burning coke exhibits, in a far more perfect manner than any steam boiler can do, the relative calorific value of coke and coal. The space within his glass pot furnace, gives abundant room for the combination of air with the gaseous products; the flames are not extinguished by comparatively cold surfaces like those of a boiler, which, after inflammation, reduce them back again into smoke; the heat requisite for perfect combustion is always present, and his furnaces are particularly favorable to the development of all the power of coal; yet he finds common *gas coke* to be superior to coals in heating power by 25 per cent.; and gas coke is stated by M. de Pambour to be found inferior to Worsley coke by 12 1-2 per cent., which no one acquainted with coke will doubt; thus exhibiting an excess over coal of 37 1-2 per cent."

Mr. Wood, in his treatise on railroads, states his experiments on locomotive boilers with *coal*, to have given a result of 4.46 pounds of water evaporated from 60° by the consumption of 1 pound of fuel; while M. de Pambour from the mean of eleven experiments on locomotive engines, burning coke, shows that the evaporative power of the latter is 6.21 pounds of water to 1 of coke, thus indicating a superiority of nearly 40 per cent. in favor of coke over coal.

From a temperature of 212° Mr. Wood's coal would have evaporated 5.12 lbs. of water, and M. Pambour's coke, 7.12 lbs. It should, however, be mentioned that in this case, the whole deficiency is not probably attributable to the inferiority of coal to coke, but in part also to the want of sufficient absorbing surface. In Mr. Wood's experiments, this was only 9.61 square feet to one square foot of grate; while in M. de Pambour's it was 47.6 feet, or nearly 5 times as much.

A knowledge of the superiority of the fixed over the volatile constituents of coal, induced the writer, in 1838, to compute and publish in the National Gazette, of Philadelphia, the relative value of some of the anthracites of Pennsylvania, and the bituminous coals in use in this and other countries. This superiority in economy for naval purposes, was predicated on two circumstances. *First*, the superior efficiency of anthracite, weight for weight; and, *second*, its greater specific gravity, by which a greater weight may be stowed in a given amount of space on shipboard. For the purposes of the iron masters and manufacturers in general, who use this fuel, for producing steam, the first consideration alone is of much importance; but this, together with questions in regard to the most economical method of burning it and applying its heat, will be found of great interest in a course of years, even where anthracite is to be had at the lowest rate.

If it can be shown that, by a judicious arrangement of boilers and grates, the cost of one or two tons of coal per day can be saved to an iron furnace, — this amount, trifling as it may seem, where coal does not cost more than one dollar per ton, at the works, may still be found to constitute the interest of a pretty large sum at the end of a year. One dollar per day is more than enough to pay the interest on the entire cost of the engine and boilers, at some of our large iron works, and certainly would amply compensate for any increased expense of boiler, which might be found necessary, in order to apply correct instead of erroneous principles of combustion.

The actual evaporative power of any fuel as determined by practice must depend both on the nature and constitution of the fuel, and on the kind of arrangement adopted to effect its combustion, whether slow or rapid, and to apply its calorific energies. Hence the importance of knowing the form of boiler, size and construction of grate, and the extent and position of heat-absorbing surfaces best adapted to give high evaporative results.

In all the iron works, using steam power, to which reference has been made in the preceding pages, the kind of boiler used is the ordinary simple cylindrical one, having neither side nor interior return flues, and consequently allowing no greater average circuit to the heated gases than from the centre of the grate to the entrance of the flue, of course less than the length of the boiler. It may on an average be computed that the absorbing surface of each boiler is one half its curved surface. Some of the experiments, which will be hereafter cited, will show how little economical such a boiler is, as compared with other forms and arrangements which might be adopted.

Among the earliest of those who have studied this subject with a view to its useful applications, may be mentioned the celebrated Mr. Watt, who at the Albion Mills, and in a wagon boiler, of the form usually adopted by him, obtained the result of 8.62 pounds of water evaporated from its initial temperature, or 9.63 from a temperature of 212° by the combustion of one pound of Newcastle bituminous coal. In later times the observations of Mr. Lean on the performance of the Cornish engines used in pumping, have put us in possession of numerous and valuable facts in regard to the evaporative power of the same species of fuel found in Wales. At first the effect of the bushel of coal was measured by the performance of the engine, to which the steam was administered, thus complicating the question of the *production* of steam with that of its *application*. More recently, however, a method has been devised for determining and registering through the agency of an apparatus which may be termed an *aquameter*, the quantity of water delivered in any given period to the boiler. By means of this registration it has been ascertained, that in the Cornish double cylindrical boilers, 36 feet long, with an exterior shell 6 feet, and an interior one of 4 feet in diameter, and affording to the flame or hot gas, a circuit of 172 feet, or a little more than four times the length of the boiler, the effect of one pound of bituminous coal is the evaporation from a temperature of 212° of 11.62 pounds of water.

An opinion prevails to some extent in this country, that the locomotive boiler is among the most economical forms of evaporating vessels; but Mr. Parkes has proved that where a pound of coal is burned in 44.03 seconds in a Cornish boiler, it produces more than twice the evaporative effect of the same weight of fuel burned in 6 3-4 seconds in a locomotive boiler; and a series of experiments made under the directions of Mr. Stevens, at Bordentown, N. J., also in a locomotive boiler, used at the time for stationary purposes, has proved that whether wood or anthracite be the fuel, an *increase* in the rapidity of combustion in the same boiler, is accompanied by a *diminution* in the evaporative efficiency of the combustible. It has also shown that the rate of diminution in evaporative effect, is within certain limits more rapid than that of the increase of combustion, in the ratio of 4 to 3. Messrs. Parkes and Manby's experiments on board the steamer "Anthracite," with Player's boiler, using anthracite coal for fuel, amply demonstrate the same general truth.

Many of the experiments of Dr. Dana hereafter cited, will be seen clearly to prove the truth of the position, that beyond certain limits an increase in the rate of combustion in any given boiler is attended with a loss of useful effect.

It is evident that the heat-absorbing surface of a steam-boiler might be so great, and the circuit to be traversed by the heat so extended, in comparison with the quantity of combustion taking place on its grate, that the hot gaseous matter would not escape until some time after it had imparted all the heat it was capable of yielding to the fluid within the boiler. In such case the gas remaining at a uniform temperature for the latter periods of its transit, would clearly not have its efficiency diminished by such an increase of combustion as should urge it with more rapidity towards its exit from the boiler. On the contrary, a farther diminution in the rate of combustion might allow the radiation and conduction of heat a greater length of time to exercise their influence in *diminishing* the evaporation. When the rapidity of combustion is such as to send the products of combustion beyond the absorbing surfaces, at a temperature greatly above that of the steam in the boiler, it is evident that some loss must be the consequence, for the escaping gas would then, if applied to a boiler within the chimney, evidently be able to generate an additional portion of steam of the same tension, since we know of no limit to the principle that a hotter body will impart heat to a colder.

Whenever, in the progress of combustion, apertures of considerable magnitude occur among the fuel, large portions of unburnt air make their way through the fire, and not only prevent the latter from doing its office for the time, but become robbers of the more useful portions of air by depriving the burning mass of its heat, which are taken away into the chimney, and dispersed at the top. All who have witnessed the effect of burning anthracite-dust with a fan blast, will have noticed the constant tendency to form little blow holes, which, enlarging by degrees, allow portions of air to become heated excessively, but not burnt. A portion of the dust is likewise projected upwards, and sent wholly beyond the seat of combustion. When coal of a large size is burned in too thin a stratum on a grate, many interstices must in like manner exist, and, in the case of dust and pea coal, the superiority of effect arising from mixing with them a portion of bituminous coal, will probably be found to depend on the partial agglutination and envelopment of the particles of anthracite in those of the coke, preventing the mobility of the former, and compelling the air to a more minute subdivision and equal distribution throughout the mass. In regard to the quality of the dust of anthracite, it may in general be regarded as quite equal in purity to that which comes to market in larger masses, since the brittleness of pure anthracite, and the toughness of slate, allows the former to be more comminuted than the latter.

On the subject of the evaporative power of bituminous coal, when employed in boilers of different forms, we have several elaborate papers by Mr. Josiah Parkes, published in the Transactions of the Institution of Civil Engineers. The table contained in the 3d vol. of that work, page 45, is particularly interesting on account of the numerous facts which it embodies, and of the conclusions to which a comparison of these may lead. A few of the data there furnished, will enable us to institute comparisons between the results of American experience with anthracite, and that of the English engineers, when using bituminous coal or coke.

"The practice of slow combustion," says Mr. Parke, "is evidently conducive to economy in the treatment of fuel."

"Boilers tested as to their merit by their respective evaporative economy, arrange themselves for consideration in the inverse order of the rate of combustion." * * *

"A second, though somewhat less regular

coincidence between the operating causes and economical results, is indicated by the extent of surface exposed to absorb the heat supplied to the boiler. * * Economy of heat is promoted in some proportion of the extent of the absorbing surface."

Mr. Parkes lays considerable stress upon the thickness of metal of which a boiler is composed, as influencing the rate of evaporation, and also on the temperature of combustion, as affecting the durability of boilers. In regard to the former of these points, I may mention that my own experiments on iron of different thicknesses, from 1-50 to 1-4 of an inch, and those of Mr. Hayes, from 1-8 up to 1 inch, prove that within these limits, which are in both directions far beyond the requisitions of the steam-boiler, no sensible difference will be produced in the evaporative effect of fuel. And with respect to the second point, I would refer to the fact, first established by my experiments, published some years since in the American Journal of Science, and since reproduced both in England and in this country, that so long as water is in contact with iron under atmospheric pressure the metal will not receive a temperature much more than 100° Fahrenheit above the boiling point; for, from 312° to 324° is reached the temperature of maximum vaporization, — a rate of generating steam far beyond the practice even in locomotive engines.

Another fact may be mentioned in proof that unnecessary stress is laid on these particulars, which is, that metallic tubes, of moderate thickness, even of copper, lead, or soft solder, when kept filled with water, may be used to traverse a fire where an intense temperature prevails, as in a grate using anthracite, without danger of melting. Years of experience have convinced me of this truth. It is also well known that in house-heating apparatus, on the hot water system, wrought iron tubes of a quarter of an inch or more in thickness, are made to pass through or around the fire, and yet remain for a long time without sensible deterioration. I have employed such an apparatus with anthracite, without the least inconvenience. *Bad* iron may suffer deterioration when used for a boiler at any temperature, and corrosive liquids, or gases, may destroy the *best*, but it is often observed that in wrought-iron heating apparatus the parts near the fire suffer less than those more remote. When a boiler is allowed to become coated with sediment, it matters little whether wood, bituminous coal, or anthracite, be the fuel. It must inevitably suffer from overheating.

The Cornish boiler combines the advantages of slow combustion, large relative absorbing surface, and great length of time for heat to remain in contact with any given portion of that surface.

## Mr. Parkes's Results

### *In the Cornish Boiler.*

" 1 lb. of coal was burnt in 44.08 seconds.

3.46 lbs. of coal was burnt on each square foot of grate per hour.

1 lb. of water was evaporated by 1 square foot of surface per hour, from 212°.

11.62* lbs. of water were evaporated by 1 lb. of coal from 212°."

*Wagon Boiler, Warwick experiments.*

"1 lb. of coal burnt under one boiler in 38.31 seconds.

4 lbs. of coal burnt on each square foot of grate per hour.

6.39 lbs. of water evaporated by 1 square foot of heated surface per hour from 212°.

10.23 lbs. of water evaporated from 1 lb. of coal, burnt from 212°."

Mr. Parkes, by a trial of 6 months' continuance, evaporated 18 1-2 cubic feet of water

---

* By assuming the latent heat of vapor to be according to the determination of Watt, only 950°, Mr. Parkes produces in this case 11.82, and in other cases, corresponding differences in evaporative results, all which I have adjusted to a latent heat of 1030°.

by 112 lbs. of coal, or 10.23 lbs. to 1 lb. of coal, from 212°, as stated in the preceding extract.

### *Wagon Boiler, mean of eight experiments.*

"1 lb. of coal burnt under one boiler in 16.57 seconds.

10.75 lbs. of coal burnt per square foot of grate per hour.

7 1-10 lbs. of water evaporated by 1 square foot of heated surface per hour, from 212°.

8.76 lbs. of water evaporated by 1 lb. of coal from 212°."

### *Locomotive Boiler.*

"1 lb. of coke burnt under one boiler in 6.45 seconds.

79.33 lbs. of coke burnt on each square foot of grate, per hour.

12 lbs. of water evaporated by 1 square foot of heated surface per hour.

7.12 lbs. of water evaporated by 1 lb. of coke from 212°.

5.70 lbs. of water evaporated by 1 lb. of coal from 212°, by calculation.

5.11 lbs. of water evaporated by 1 lb. of coal from 212°, by Wood's experiment."

### BITUMINOUS COAL IN MARINE BOILERS.

Mr. Tredgold gives, in his Treatise on the Steam Engine, an account of an experiment on board the steamer African, in which 306 cubic feet of fresh water were evaporated by the consumption of 24 cwt. of Heaton coal. This is 19,125 lbs. of water raised into steam by 2,688 lbs of coal, from the initial temperature, presumed to be 60°. To compare this with other results above mentioned, we find that 7.11 lbs. of water were evaporated by 1 lb. of coal from 60°, and that $\frac{1182}{1030}\times 7.11 = 8.15$, were obtained from 212°.

## MR. PLAYER'S METHOD OF BURNING ANTHRACITE.

Mr. Player has invented a method of supplying anthracite to the furnace of a steam boiler, a description of which is contained in the 8th vol. of the Reports of the British Association, transactions of sections, p. 130. "The coal is heated before it reaches the fire. It is supplied to the grate through a perpendicular chamber, placed centrally on the top of the boiler, with an opening about 20 inches in diameter, immediately over the fireplace. In passing through this chamber, by its contact with the plates, the coal acquires considerable heat, and descending by its own gravity as the fire consumes beneath, replaces what has been burnt; by which means a regular supply of fuel is furnished, fit for immediate and complete ignition. The action of the fire is regular, not checked at any time by fresh applications of cold fuel. The fire is never meddled with; there are no fire-drawers, no currents of cold air passing through the flues. One engine worked 72 hours consecutively, during which time the grate neither choked nor clinkered, nor was a bar used for the fire, or did there remain any considerable result in ashes. The coal was in this instance entirely anthracite (small but not powdery) and tipped into the feeding chamber once every four hours. Water was kept in the ash pit, and being converted into steam, aided, to some extent, the production of flame. Smith's fires are worked on a similar principle, and a foundry, with a flue to take off the flame, is managed on the plan of heating the fuel, to avoid clogging the fire by the splintering up of anthracite, when suddenly exposed to a high temperature."

In regard to the method of Mr. Player, it may be remarked, that few only of the anthracites of Pennsylvania require us to guard against the evil which this invention is intended to obviate. Smithwork, melting iron, and generating steam are all now effected without a resort to any expedient to prevent the comminution of the coal.

On the efficacy of Mr. Player's invention, in promoting evaporation, we have two reports; one from Messrs. Dr. Charles Schauffheautl and William Bevan, and the other from Messrs. Josiah Parkes and C. Manby, from which the following abstracts are taken.

### *From the Report of Dr. Charles Schaufheautl and Mr. William Bevan.*

"Pure charcoal (procured from the distillation of sugar), has been found by Despretz to be capable of evaporating 12.$^3$ times its own weight of water, at 32°, and under a pressure of one atmosphere. This is therefore a standard measure to which all other fuels may be compared." At 212° it is 14.45 pounds to 1.

"To evaporate this quantity of water, 1 lb. of pure charcoal must combine with 2.6166 pounds of oxygen. As hydrogen is likewise a component part of many fuels, that also must be taken into account. In combustion, hydrogen combines with 8.009 times its own weight of oxygen, and the quantity of heat evolved, as compared to carbon, is in the same ratio as the quantity of oxygen with which they combine in burning."

*Analyses of Swansea Anthracite.*

| | |
|---|---|
| " Carbon . . . | 92.42 |
| Hydrogen . . . | 3.37 |
| Oxygen . . . | 1.43 |
| Nitrogen . . . | 1.05 |
| Sulphur . . . | 0.12 |
| Ashes and loss . . | 1.61 |
| | 100. |

Sp. Gr. . . . . 1.413

*Another Specimen.*

| | |
|---|---|
| Water . . . . . | .300 |
| Oxide of iron . . | .264 |
| Alum . . . . . | .478 |
| Silica . . . . . | .190 |
| Hydrogen . . . | 2.390 |

| | |
|---|---|
| Oxyde of iron . . | 1.336 |
| Azote . . . . . | 0.876 |
| Carbon . . . | 94.100 |
| Sulphur trace | |
| Loss . . . . | 0.068 |
| | 100. |

| | | | |
|---|---|---|---|
| 92.42 | carbon require | 241.825 | oxygen |
| 3.37 | hydrogen | 27.017 | " |

Hence 268.842 represents the total amount of oxygen required."

"The anthracite contains 1.43 oxygen in a fixed state, and as the sulphur and iron in the sulphuret, combine during combustion with 0.16 oxygen to form sulphurous acid and oxide of iron, these quantities of oxygen must be subtracted; viz. 1.43 + 0.16, leaving 267.252 as the total quantity, or 2.67 pounds of oxygen to consume 1 pound of anthracite; and since pure carbon only requires 2.6166, we may safely assume, that 1 pound of the anthracite used in our experiment, (and which was not like the sample analyzed, perfectly free from heterogeneous matter), is able theoretically to evaporate 12.3 pounds of water at 32°.

| | |
|---|---|
| Surface of boiler, horizontal | 22.5 |
| “ “ “ vertical | 171.87 |
| Total equivalents | 194.37 ” |

“ The vertical being reduced to horizontal surface, we have for total effective surface 65.5 superficial feet.

Thickness of boiler plate 1-4 inch.

Boiler contained 62 cubic feet of water, 29 cubic feet of steam.

The area of fire bars was 7 superficial feet.

The mass of fire 10 cubic feet.

The mass of coal in the feeding-chamber, 5.5 cubic feet.”

“ The pressure on the boiler was constantly equal to 1.909 atmospheres or 13.64 pounds per square inch, and the steam was kept up with great regularity.”

"During the experiment the average height of the barometer was 29.18 inches, that of the thermometer, 45.5°.

The anthracite consumed during the twelve hours, amounted to 372.28 pounds, and the water evaporated by it reduced to 32°, was 3934.3 pounds: therefore, 1 pound of anthracite, evaporates 10.56 pounds of water under a pressure of 1.909 atmospheres, or 11.11 pounds of water under 1 atmosphere; from which it appears, that the actual loss of caloric, taking the theoretical standard, 12.3 pounds water to 1 pound of anthracite, only amounted to 0.096, and consequently, it is not quite one tenth part."

Reducing 10.56 at 32° to 212° we obtain 12.4 pounds of water to 1 of steam, which makes the result comparable with those given in the preceding and following pages.

## *Extracts from the Report by Josiah Parkes and C. Manby, Civil Engineers.*

"The boiler (on board the steamer Anthracite) was too small to develope the full effect of the fuel ; the draught was too weak to vary sufficiently the quantity of evaporation per hour.

| Experiment. | Coal burnt per square foot of grate per hour. | Water evaporated from 212° per hour. | Water evaporated from 212° by 1 pound of anthracite. | Water evaporated from 212° by 112 pounds of anthracite. |
|---|---|---|---|---|
| | lbs. | | | cubic feet. |
| 1 | 14.86 | 1963.89 | 6.44 | 11.66 |
| 2 | 12.65 | 2240.00 | 8.13 | 14.86 |
| 3 | 3.18 | 833.02 | 12.15 | 21.94 |
| 4 | 2.94 | 867.44 | 13.35 | 24.18 |

Water reduced to 212°.* Air went into the chimney in the first and second experiments, hot enough to melt zinc, even on the third and fourth experiments, when 2-3 of the chimney was closed."

---

* 15° of the heat is computed to be carried up the chimney with the burnt air.

"Comparing the mean of the two highest with the two lowest results, it appears that by increasing the rapidity of combustion in the ratio of 4.49 to 1, the evaporation in equal times was increased only in the ratio of 2.47 to 1, whilst the evaporative product from equal weights of coal, was diminished in the ratio of 1.74 to 1."

"Recorded experiments with the Welsh coal in Cornish boilers, show, that at the same rate of combustion, as in our fourth experiment, viz.; 2.94 pounds per square foot of grate per hour, the evaporative product was 21.31 cubic feet from 212° by 112 pounds of coal, or 11.78 pounds by 1 pound of coal."*

"Under like rates of combustion, therefore, the anthracite exceeded the Welsh coal in the ratio of 13.35 to 11.78, or by 13 per cent,— but the relative area of the heat absorbing surfaces, the period of the duration of the heat about those surfaces, and the radiating condition of the exterior of the respective boilers —

---

* See table of boilers, experiment 1, Transactions of Institute of Civil Engineers, part I., Vol. III.

all which circumstances materially influence the realization of high evaporative product, — are so much in favor of the Cornish, compared with the "Anthracite" boilers, as to justify the inference, that if our experiments could have been conducted under equally favorable circumstances with those of the Cornish boilers, the results would have been considerably greater than those we actually obtained."

"The Cornish boiler presented an area of 961.66 square feet, and the "Anthracite's" boiler 340 square feet, to receive the heat generated from equal weights of coal and of anthracite, in equal times = 2.549 to 1 in favor of the former."

"The rates of combustion and consequently the velocity of the current of heat from the grates were equal. The distance passed over, or circuit made by the heat, after quitting the grates, was 152 feet in the Cornish, and 3 feet in the "anthracite" boiler; and the period of the duration of the heat about equal; surfaces of the two boilers were 2 1-2 times larger in the Cornish boilers than in those of the "anthracite." The Cornish boiler was enveloped in good non-conducting substances, that of the "Anthracite" had little or no defence against loss from radiation; considering these differences, and their influence over evaporative economy, we are of opinion, that under equal circumstances, anthracite would greatly exceed the best bituminous coal in calorific value, it having already given, even under comparatively unfavorable circumstances, a result greater by 13 per cent. than any on record. The highest known evaporative product, from New Castle and Staffordshire coal, is 10.23 pounds at 212° by 1 pound of coal, obtained at Warwick.* Our fourth experiment with anthracite exceeded the Warwick experiment 30 per cent. Mr. Player's method of supplying anthracite, dispenses with all mechanical means; with the labor of stoking, and with the waste and injury arising from the common system of firing by the shovel through the fire door. No stoking in general takes place during the day."

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* Trans. Inst. Civ. Eng., Part I., Vol. III.

"When working with the damper the coal descended so uniformly, that the water tank, which held 400 pounds, was emptied so nearly in equal times, as scarcely to vary a single minute for hours together. The coal descended upon the fire precisely at the rate required by the combustion; no scoriæ were produced; the quantity of ashes was very small."

## DR. FYFE'S EXPERIMENTS.

On the 8th of February, 1841, Dr. Andrew Fyfe, President of the Society of Arts for Scotland, read before that Society a paper on the evaporative power of different kinds of coal, in which he compares the efficiency of Scotch and English bituminous coals with that of anthracite, or what he terms such, though with us it would be called transition, or semibituminous coal. By his analysis it appears to have possessed 17.8 per cent. of volatile matter, including 4.4 per cent. of water, and 10.8 per cent. of earthy matter, leaving of course, but 71.4 per cent. of fixed carbon. It had a specific gravity of from 1.303 to 1.406. Indeed, so far as the proportion of its three proximate constituents can be relied on to indicate the character of coal, it appears to be nearly identical with several of the free-burning coals contained in Table IV.

His first trial was upon Scotch coal, containing 42 per cent. of volatile matter, including 7.5 of water, and only 50.5 per cent. of fixed carbon. This coal, burned under a boiler working at 17 lbs. pressure, evaporated 4880 lbs. of water from a temperature of 45° Fah. by the combustion of 732 lbs. of the fuel, or 6.66 lbs. of water, by 1 lb. of coal. Reducing this to the standard of 212°, we have 7.74 lbs.

This and the other experiments of Dr. Fyfe are contained in the following Table, in which I have reduced them to the temperature of 212°, in order to render the results comparable with others, hereafter to be noticed. Little or no attention seems to have been paid in these experiments to the rate of combustion, without which nothing can be inferred in regard to the relative values of fuel.

# TABLE V.

DR. FYFE'S *Experiments to compare Scotch and English bituminous coals with anthracite, in regard to their evaporative power, in a high pressure boiler of a* 4 *horse engine, having a grate with* 8.15 *square feet of surface. Also in a wagon-shaped copper boiler, open to the air, surface* 18 *feet, grate* 1.55.

| No. of Experiment. | Kind of fuel employed. | Pounds burnt per hour on the grate. | Duration of the trial in hours | Temperature of the water. | Pounds of water evaporated from the initial temperature by 1 lb. of coal. | Pounds of water at 212° from 1 lb. of coal. | Coal per hour on 1 square foot of grate. | Time in seconds of consuming 1 lb. of coal. | Pounds evaporated per hour from each square foot of surface. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Middlerig Scotch coal. | 81.33 | 9 | 45° | 6.66 | 7.74 | 10.00 | 44.27 | | Pressure 17 lbs. per sq. inch. |
| 2 | Scotch coal, different variety from preceding. | 108 | 5 | 170 | 6.62 | 6.89 | 13.25 | 33.33 | | Do. |
| 3 | Anthracite, origin not given. | 47.94 | 8½ | 45? | 8.73 | 10.10 | 5.88 | 75.09 | | Do. |
| 4 | Scotch coal, from near Edinburg. | 8·24 | 8¼ | 50 | 5.88 | 6.90 | 5.31 | 436.89 | 3.15 | Low pressure open cop. boiler. |
| 5 | English bituminous coal. | 6.07 | 8.4 | 50 | 7.84 | 9.07 | 3.91 | 593.08 | 3.06 | Do. |

We come next to an examination of what has been done in the United States, towards gaining a knowledge of the evaporative power, and the best modes of employing anthracite for generating them. Here, as in the various domestic uses, the smelting and puddling of iron with anthracite, and its employment for locomotives, and for steamboats, we shall find our countrymen have not been behind Europeans, either in the time, or in the magnitude of their labors.

## Mr. A. A. Hayes's Experiments.

The following interesting extracts were, by the kindness of my esteemed friend, Dr. Dana, and the politeness of the writer, placed at my disposal. They serve to show how early, and how successfully, the attempts to economise fuel, particularly anthracite, have been prosecuted in this country.

"Roxbury Laboratory, Dec. 19, 1839.

"Dr. Samuel L. Dana,

"My Dear Sir,

"I feel gratified in learning that the results obtained with our boilers have excited your interest, and it will afford me pleasure to state particularly the facts in reply to your queries.

"1. *The size of our boilers?* They are 18 feet long, 24 inches in diameter inside, and, I think, 3-8 inch thick.

"*Size of grate surface?* There are 18 square feet, 6×3, but the spaces, each 1-4 inch wide, are 19 in number, there being 18 bars, 2 inches wide, including spaces, to make the width, and 3 lengths, of 3 feet each, to make the length.

"3. *The pressure?* Our valves are kept loaded with 45 pounds per square inch. While working, these are in motion about one third part of the time. Our engine has the usual dimensions of a 10 horse engine, and while we are taking off steam for the kettles, works rapidly; at other times it is irregularly attended.

"4. *The quantity of coal consumed?* The largest consumption we have known is 2060 pounds of a mixture of small anthracite, 3 parts by weight, and small Sydney, 1 part, in 12 hours. Sometimes our engine works half the day, with a less consumption of fuel before the kettles are ready for the steam; we then urge the fire, and in 6 or 7 hours evaporate as much water as the boilers will allow. Had we use for the whole steam regularly each day of 12 hours, we could supply 20,000 lbs. The trials we have made have been conducted as follows. In the morning 25 to 30 lbs. of flour barrel staves were thrown on a clear grate, fire applied, and coal added. Water at 60° Fah. pumped in by hand until at the level of the guage cock, the safety valve being open. The measure-cistern was then filled to the edge. It has a flow pipe, 3 inches from the bottom, and contains 3437 lbs. above the flow pipe. The forcing pump lost no water in its strokes. The usual workings of the kettles being continued during the day, at night the fuel on the grate was raked off into the ash pit, which has some inches of water constantly on its bottom. In the morning the unconsumed fuel was separated from the ashes and mixed with that to be used during the day. Water from the cistern was then allowed to flow in so as to attain the initial height in the boiler, and the weight of the coal ascertained for the day of 11 to 12 hours firing."

"Instead of one day's working, we have weighed in 5 tons of mixed coal, and counted our water for 6 days, deducting unconsumed fuel. In this way, the account always exceeds the mean of 3 days, owing to the increased heat of the flues. Taking 3 days, the mean of water used was 18,903 lbs., and of mixed coal 1827 lbs. The idea of giving the present form to the arrangement was borrowed from the Annales d'Industrie, 1st vol., after I had fully satisfied myself of the inutility of the tubular boilers. In the form adopted, a great improvement is made over the arrangement alluded to, in giving more surface to the fire. The air which passes the dampers will not melt lead, although a feeble flame of burning carbonic oxide is seen within 3 feet of them. Considering one half of the surfaces of the upper boilers exposed to flame, we have 338 feet of heated surface, and an evaporating power of 5 lbs. per foot.

" The grates are 7 inches from the nearest surface of the lower boilers, and the fuel is kept *3 to 4 inches in thickness on the grate.* There are dust holes for ease in removing ashes weekly, and the fire door is 4 inches below the grates. The boilers are 5 inches apart (that is, from upper to lower,) and, side and side, the distance is 3 inches at the nearest point. You will readily perceive that the intention is to expend the intensity of the fire on the lower boilers, which are full of water ; for that reason the side flues are brought within 4 inches of the boilers, while they are quite free above ; the effect is, to cause the flame which passes between the lower boilers, to strike the upper ones, and then descend under them to the side flues, wrapping them in flame."

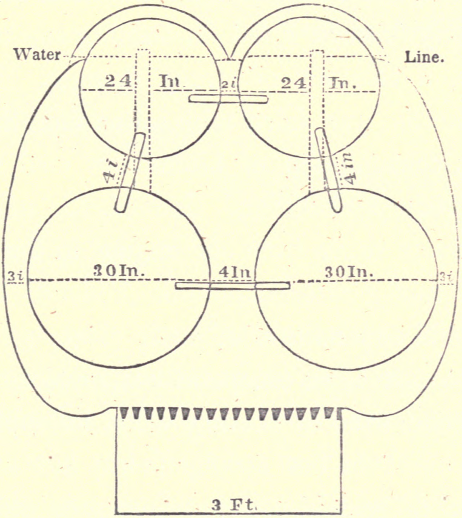
" The secret of the economy of fuel under the Cornish boilers, is, I think, fairly revealed, when we know their surfaces and mode of firing. In using bituminous coal, fully 1-10 will be saved by heavy charging on a platform in front of the grates, and in so managing as to burn the vapors and gases.

"I have seen 4 boilers, with large inside flues, heated by anthracite, under a blast from a fan, where the gases passed under and around the bridge, through the flues surrounded by water, at 216° Fah., then mixed and entered a chimney, where they burnt in a volume 40 feet high. — In comparing our results with any other, I have no data. The available heat from anthracite coal certainly exceeds that from an equal weight of coke, and another element in the calculation is introduced, when we know that 1-10 part of the fuel in an ignited state is in contact with the surface of the boiler in the form of particles forced in contact by the blast. On trying a fire of the best coal, in fragments of 2 and 3 inches square, we were unable to work our kettles, and compelled to withdraw the fuel, and use the kind adapted to the form of grate we adopted. I have been in the neighborhood of many trials of tubular boilers, and conclude from their history so far, that when the tubes are small, they are very uneconomical and troublesome; that the best results are obtained from passing the heated air and gases under long boilers, so that a radiating surface of brick may form a part of each flue, and thereby consume the combustible part of the gases. The study of these matters, more than any thing else, has shown me how slowly we glean a little knowledge; in fact it is strange that among such a number of eminent engineers as England possessed, and with such a vast amount of property hazarded, so little is known of the phenomena attending the combustion of coal. The question, what becomes of the 25 parts of matter, which should produce nearly as much heat as the 75 of carbon, remaining in 100 of coal? has never been answered, so far as I can learn.

"Yours, respectfully,

(Signed) "A. A. Hayes."

The following figure will render intelligible Mr. Hayes's present plan of arranging 4 cylindrical boilers within a furnace; boilers 20 feet long, grate 3 feet wide by 6 long.



*Extract from a letter from A. A. Hayes, Esq. to Dr. Samuel L. Dana, dated*

Roxbury, December 25, 1839.

"In relation to flues within boilers, we were at the expense of testing their value. The apparatus used was a lead kettle 27 feet long, about 3 feet wide, 2 feet deep, through which a plate iron tube, 1-6 inch thick, 18 inches diameter at one end, 10 inches at extreme end, covered with 6 lb. lead, was passed. The large end entered the chamber of a reverberatory furnace fitted for burning smoke, the other, a chimney of strong draught. When the kettle was filled with saline fluid the utmost, consumption of bituminous coal would not produce ebullition. Indeed, the effect of the waste steam from our engine in the same tube was greater than that produced by the wasteful expenditure of coal. I am perfectly well aware of an escape of heat, which might be economized in heating water for supplying the boilers in our arrangement; but the expense of vessels, &c. has prevented me from using it. Were it necessary to produce a large quantity of steam here, I think I should keep the evaporating power up to 6 lbs. per square foot for anthracite, and economize any excess of heat by separate vessels. In burning anthracite I do not think more than 1-5 of the oxygen in the air passed, is consumed, unless the coal is at its highest point of combustion, and a large fire seems the more ready way of approaching this state.

"Dr. Ure has lately compared anthracite with the best steam generating coal in England, and he gives anthracite 13 produce, coal 9 1-2 to 10."

### *Dr. Dana's Experiments.*

Dr. Samuel L. Dana, of Lowell, Massachusetts, has made experiments on six or seven different arrangements of boilers, viz.

1. On two cylindrical boilers set together, 20 feet long and 30 inches in diameter.

2. On two similar boilers, 20 feet long, 45 inches in diameter.

3. On three cylindrical boilers, arranged within the same furnace, two being *suspended* side by side, about 3 inches apart; and a third, with its central line above the centre of this space.

4. On four cylindrical boilers, arranged ac-

cording to the plan of Mr. Hayes, already described.

5. On a tubular boiler, constructed on the general plan of locomotive boilers, but of greater length, and having only 12 tubes of 3 inches in diameter.

6. On a double cylindrical boiler, of the Cornish form, and set in the usual mode practised in Cornwall.

7. On the same boiler, altered by inserting in the interior cylinder, three cylindrical boilers; two on a level with each other, and one above the dividing line between them, leaving spaces all round them for the heat to play on their whole surfaces.

From his minutes on the action of all these boilers, Dr. Dana has very kindly furnished me with the data necessary to make the calculations of the following tables. All who are interested in the subject of fuel will duly appreciate the important labors of Dr. D. in endeavoring to devise a form of boiler which should combine all the requisites of high evaporative efficiency with simplicity of construction, facility of cleaning, and easy access to the parts in case of making repairs. The interest of those who furnish anthracite to the market, will obviously be promoted by whatever demonstrates its efficacy and the best modes of its application.

Besides the forms of boiler above mentioned, Dr. Dana has made other arrangements, some of which are highly successful, more particularly one set of five boilers, 36 feet long, of which three are laid or rather *suspended* at the same level, side by side, at 2 or 3 inches apart; and two others, each above one of these spaces, between the lower boilers. This arrangement will be seen to differ from that of Mr. Hayes, in the circumstance of the latter placing the upper boiler vertically over the lower; and Dr. Dana, over the centre line of the interstices, between two adjacent lower boilers. The results obtained with this arrangement, are not contained in any of the tables, but are understood to be about equally favorable with those derived from the combination of three boilers. In all the arrangements at Lowell, the grates are set 7 inches below the lower periphery of the lower boilers, and the chimneys, with which their flues are connected, are 80 feet high. Three large circular chimneys, of this height, are on the premises. The pressure of steam never exceeds 4 1-2 pounds per square inch. It is measured by a glass syphon gauge. The water is measured before going into the boilers, by a large rectangular cistern, and is fed to the boiler according to its actual demands, as indicated by a float, which moves a valve in the supply pipe. The stock of fuel in the establishment is well secured against moisture.

## TABLE VI. — PLAIN CYLINDRICAL BOILERS.

DR. DANA'S *Experiments on two plain cylindrical boilers, set in the usual way, side by side, and having one grate three feet wide by six long, common to the two. Each boiler is* 20 *feet long and* 30 *inches in diameter. Two thirds the curved surface being exposed to the fire, there are of course* 209.44 *square feet of heated surface, and consequently the number of feet of heated boiler surface for one of grate surface, is* 11.63.

| No. of the Exper. | Kind of Fuel employed. | Number of pounds of fuel consumed per hour. | Duration of the trial, in hours. | Temperature of the water before being put into the cistern. | Pounds of water at the initial temperature evaporated by one pound of fuel. | Pounds evaporated from 112 degs. by one pound of fuel. | Pounds of coal burned on one square foot of grate, per hour. | Time, in seconds, of burning a pound of coal. | Weight of water evaporated from one square foot of heated surface per hour, from 212 degrees. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | White's Philadelphia pea coal | 166½ | 10 | 32° | 7.92 | 9.30 | 9.25 | 21.62 | 7.39 | If we compare the mean evaporative result of Nos. 1 and 2 with that of 5 and 6, we find that the former is nine pounds of water generated into steam by one pound of coal in 20.83 seconds, while the latter is 7.98 pounds, raised in like manner in 19.26 seconds; a difference of 12.78 per cent. in favor of slow combustion. |
| 2 | .......... Ditto ............ | 179½ | 10 | 32 | 7.41 | 8.70 | 6.97 | 20.08 | 7.46 | |
| 3 | .......... Ditto ............ | 180 | 10 | 32 | 7.69 | 9.03 | 10.00 | 20.00 | 7.76 | |
| 4 | .......... Ditto ............ | 182 | 10 | 32 | 6.53 | 7.67 | 10.11 | 19.78 | 6.18 | |
| 5 | .......... Ditto ............ | 192 | 6½ | 32 | 7.06 | 8.29 | 10.66 | 18.75 | 7.60 | |
| | Mean of 5 experiments = | 180 | 9.3 | 32 | 7.32 | 8.60 | 10.00 | 20.04 | 7.28 | |
| 6 | Sydney coarse coal, burned without blast. .. | 198 | 10 | 32 | 6.05 | 7.11 | 11.00 | 18.18 | 6.72 | Comparing the evaporation per pound with Sydney bituminous coal, as given in experiment 6th, with the mean of the trials on White's pea coal, we find the latter to be 19.95 per cent superior to the former. |
| 7 | .......... Ditto ............ | 200 | 11 | 32 | 6.00 | 7.05 | 11.11 | 18.00 | 6.72 | |
| 8 | .......... Ditto ............ | 227 | 10 | 32 | 6.30 | 7.40 | 12.61 | 15.86 | 8.02 | |
| | Mean of 3 experiments = | 208.3 | 10.33 | 32 | 6.11 | 7.18 | 11.57 | 17.34 | 7.15 | |
| 9 | Philad. pea coal, mean of ten days' running. .. | 100 | 10 | 32 | 8.07 | 9.48 | 5.55 | 36.00 | 4.53 | This experiment gives a superiority of 10.02 per cent over the mean of 1—5, the rate being in this experiment 100 pounds and in the former trials 180 pounds of coal burned per hour. |

## TABLE VII. — CYLINDRICAL BOILERS.

*Experiments on two old cylindrical boilers, which had been in use ten years—each* 20 *feet long*, 45 *inches in diameter, set side by side, with a grate under each, seven inches below, five feet long and two and a half feet wide, with a wall rising between them, but not to the height of the boiler. Thus the flames from the two grates came together. Total grate surface* 25 *feet ; total heated surface* 255.4 *feet—square feet of heated surface to one foot of grate surface*, 10.21. *In these experiments the firemen were allowed to stoke according to their previous habits—no directions were given them. Made in the summer of* 1840.

| No. of the Exper. | Kind of Fuel used. | Pounds burned per hour on the whole grate. | Duration of the experiment, in hours. | Temperature of the water when received to tank. | Pounds of water to one of coal, from initial temperature. | Pounds of water to one of coal, from 212 degrees. | Pounds of coal burned on one square foot of grate, per hour. | Time, in seconds, of burning one pound of coal. | Pounds of water per hour, from one square foot of heated surface. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | White's best Peach Mountain anthracite ...... | 183 | 12 | 70 | 8.40 | 9.56 | 7.32 | 19.67 | 6.83 | From the first to the tenth experiment a fan blast was used. Between burning a pound of coal in 13.1 and in 19.67 seconds, there seems to be a difference in effect in favor of slow combustion, of more than 32 per cent. as given by the difference between experiment 1 and experiment 3. |
| 2 | ...... Ditto ........ | 256 | 12 | 70 | 6.33 | 7.20 | 10.24 | 14.06 | 7.23 | |
| 3 | ...... Ditto ........ | 290 | 12 | 70 | 6.36 | 7.24 | 11.60 | 13.10 | 8.23 | |
| | Mean of 3 = | 243 | 12 | 70 | 7.03 | 8.00 | 9.72 | 15.61 | 7.43 | |
| 4 | Beaver Meadow..... | 147 | 12 | 70 | 8.00 | 9.10 | 5.88 | 24.49 | 5.24 | Here the effect of rate of combustion is less sensibly manifested than in the preceding set; but the difference is still 6.8 per cent between burning a pound in 15½ and in 24½ seconds. |
| 5 | ...... Ditto ........ | 208 | 12 | 70 | 8.04 | 9.15 | 8.32 | 17.30 | 7.44 | |
| 6 | ...... Ditto ........ | 233 | 12 | 70 | 7.40 | 8.42 | 9.32 | 15.45 | 7.64 | |
| | Mean of 3 = | 196 | 12 | 70 | 7.81 | 8.89 | 7.84 | 19.08 | 7.08 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Anthracite dust one half, Sydney slack one half... | 233 | 12 | 70 | 6.50 | 7.40 | 9.32 | 15.45 | 6.76 | This mixed fuel appears to be 13.5 per cent. inferior in power to Beaver Meadow anthracite. |
| 8 | Three fourths fine anthracite, one fourth bitum. | 191 | 12 | 70 | 7.22 | 8.41 | 7.64 | 18.85 | 6.68 | Between 7.02, the result when a pound of coal is burnt in 11.8 seconds, and 8.41, the effect obtained by burning it in 18.8 seconds, the difference is 1.39 pounds, or 19.7 per cent. of the former weight of steam produced. |
| 9 | ...... Ditto ........ | 191 | 12 | 70 | 6.26 | 7.12 | 7 64 | 18.85 | 5.33 | |
| 10 | ...... Ditto ........ | 305 | 12 | 70 | 6.17 | 7.02 | 12.20 | 11.80 | 8.39 | |
| | Mean of 3 = | 228.3 | 12 | 70 | 6.55 | 7.51 | 9.16 | 16.50 | 6.80 | |
| 11 | Coarse Sydney bituminous coal, no blast......... | 300 | 12 | 70 | 5.31 | 6.04 | 12,00 | 12.00 | 7.10 | Experiment 19 gives a result corresponding with *this* in rate of combustion, but gives a produce of steam by Lackawanna coal of 8.00 instead of 6.04. Difference in favor of anthracite, 32.4 per cent. |
| 12 | White's Peach Mountain | 229½ | 12 | 70 | 7.22 | 8.21 | 9.18 | 15.68 | 6.98 | The differences in rate of combustion are here so slight, that their influence is masked by irregularities of firing, and other causes already alluded to. |
| 13 | ...... Ditto ........ | 241¾ | 12 | 70 | 7.30 | 8.30 | 9.67 | 14.89 | 7.85 | |
| 14 | ...... Ditto ........ | 245 | 10 | 70 | 7.09 | 8.07 | 9.80 | 14 69 | 7.74 | |
| 15 | ...... Ditto ........ | 246 | 11 | 70 | 7.66 | 8.72 | 9.84 | 14.65 | 8.41 | |
| | Mean of 4 = | 240½ | 11.25 | 70 | 7.42 | 8.43 | 9.62 | 14.98 | 7.75 | |
| 16 | Coarse Lackawanna | 217 | 12 | 70 | 8.50 | 9.67 | 8.68 | 16.59 | 8.23 | With one exception, the results of this set of experiments follow the reverse order of the rapidity of combustion; a pound of coal burned in 12 seconds produced 8 pounds of steam, burned in 16.6 seconds, its produce was 9.67 pounds of steam. Gain by slow combustion, 20.67 per cent. |
| 17 | ...... Ditto ........ | 232 | 12 | 70 | .01 | 10.25 | 9.28 | 15.51 | 9.32 | |
| 18 | ...... Ditto ........ | 248 | 12 | 70 | 7.71 | 8.77 | 9.92 | 14.51 | .52 | |
| 19 | ...... Ditto ........ | 300 | 12 | 70 | 7.03 | 8.00 | 12.00 | 12.00 | 9.40 | |
| | Mean of 4 = | 249.2 | 12 | 70 | 8.07 | 9.17 | 9 97 | 14.65 | 8.87 | |

The kinds of anthracite which Dr. Dana has chiefly used, are Lackawanna, Peach Mountain, Lehigh and Beaver Meadow; and between these there does not appear to be a very important difference in efficiency. The Beaver Meadow and Lehigh gave results so nearly alike, as scarcely to require a distinction to be made, and the other two kinds are also pretty nearly on a par with each other. When the Cornish boiler, altered by putting in three interior cylinders, was newly fitted up, the result for days together was 13 1-4 pounds of water to the pound of anthracite, of Beaver Meadow, evaporated from the *initial temperature*, or 15.56 pounds from 212°.

In some cases the result reached above 14.5 pounds to one of coal, (= 16.64 lbs. from 212°), but of these only a few were obtained.

Other results will be readily learned by an inspection of the preceding and following tables.

## TABLE VIII. — EXPERIMENTS ON THREE CYLINDRICAL BOILERS.

*These boilers are* 36 *feet long and* 30 *inches in diameter, two being laid side by side, with an interval of about three inches between them ; the third is centrally placed a few inches above this interstice. The whole surface of the two lower boilers and two thirds that of the upper one, are exposed to the action of the heat. Hence the entire absorbing surface is* 754 *square feet. The grate is three feet wide and five feet long, consequently its surface is fifteen square feet, and the number of feet of heated surface is* 50.26 *times as great as that of grate surface. The grate is seven inches below the lowest part of the two lower boilers. By proper tubes the steam and water chambers are connected together, and the lower boilers are kept full of water.*

*These experiments were made on six consecutive days, in the winter of* 1840–1841.

| No. of Exper. | Kind of Fuel used. | Pounds burned per hour on the whole grate. | Duration of the experiment. | Temperature of the water when received into the boiler. | Pounds of water evaporated by one pound of coal from initial temp. | No. of pounds evaporated from 212 degs. by one pound of coal. | Pounds of coal burned on one square foot of grate, per hour. | Time in seconds, in burning one pound of coal. | Pounds of water evaporated per hour from one square foot of heated surface, from 212 degs. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | h'rs. | degs | | | | | | |
| 1 | Coarse anthracite.... | 142 | 10 | .. 32 .. | 10.61.. | 12.45.. | 9.46.. | 25.35 | ....2.34.... | The experiments in this table indicate a considerable diversity in the mode of "firing," and the diversities in the 7th column are such as to lead to the supposition that some error may possibly have occurred in noting the results. But even admitting them to be correctly given, we see that the first three, compared with the last three, give to the former set a superiority of 0.99 pounds, or 9.3 per cent. in the evaporative power of the fuel, by burning one lb. in 23.95 instead of 20.08 seconds. |
| 2 | ...... Ditto ........ | 142 | 10 | .. 32 .. | 9.81.. | 11.52.. | 9.46.. | 25.35 | ....2.17.... | |
| 3 | ...... Ditto ........ | 170 | 10 | .. 32 .. | 9.19.. | 10.79.. | 11.33.. | 21.17 | ....2.43.... | |
| | Mean of first 3 = | 151.3 | 10 | .. 32 .. | 11.19.. | 11.59.. | 10.08.. | 23.95 | ....2.31.... | |
| 4 | ...... Ditto ........ | 174 | 10 | .. 32 .. | 9.00.. | 10.56.. | 11.60.. | 20.69 | ....2.43.... | |
| 5 | ...... Ditto ........ | 180 | 10 | .. 32 .. | 8.94.. | 10.49.. | 12.00.. | 20.00 | ....2.50.... | |
| 6 | ...... Ditto ........ | 184 | 8 | .. 32 .. | 9.16.. | 10.75.. | 12.26.. | 19.56 | ....2.62.... | |
| | Mean of 3 = | 179.3 | 9.33 | .. 32 .. | 9.03.. | 10.60.. | 11.95.. | 20.08 | ....2.51.... | |

## TABLE IX.

Dr. Samuel L. Dana's *Experiments on the Evaporative Power of different Coals, under a set of four boilers arranged on the plan of Mr. A. A. Hayes's; each boiler being twenty feet long, and two feet in diameter; the grate six feet from front to rear, and three feet wide—the absorbing surface of boilers exposed to the heat 338 square feet. Distance from the centre of the grate to the entrance of flue 27 feet.*

| | Kind of Coal used. | Pounds burnt per hour on the grate. | Duration of the trial, in hours. | Temperature of water. | Pounds of water evaporated from the initial temperature by one pound of coal. | Pounds of water evaporated from 212 deg. to one of coal burned. | Coal in pounds burnt per hour on one sq. foot of grate. | Time of burning one pound of coal, in seconds. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Sydney bituminous of usual size, screened from small and dust | 250 | 12 | 44° | 5.01 | 5.83 | 14.16 | 14.4 | Burned without blast. |
| 2 | Three parts anthracite dust—one part of Sydney slack | 168 | 7 | 44 | 8.11 | 9.43 | 9.30 | 21.43 | |
| 3 | Ditto | 137 | 20 | 44 | 8.58 | 9.98 | 7.61 | 26.27 | Burned with fan blast; fan making about seven hundred revolutions per minute. |
| 4 | Ditto | 137 | 3 | 44 | 10.55 | 12.27 | 7.61 | 26.27 | |
| 5 | Ditto | 124 | 12 | 44 | 8.00 | 9.30 | 6.33 | 29.03 | |
| | Mean of 4 experiments = | 141.5 | 10.5 | 44 | 8.81 | 10.24 | 7.71 | 25.75 | |
| 6 | Same mixture as the preceding | 62.5 | 8 | 44 | 9.50 | 11.01 | 3.47 | 57.60 | With blast as above. From this and the preceding set, it appears that a gain of 10.9 per cent results from diminishing the rate of combustion from 141 to 67 pounds per hour. |
| 7 | Ditto | 66 | 5 | 44 | 10.47 | 12.13 | 3.66 | 54.54 | |
| 8 | Ditto | 70 | 8 | 44 | 10.41 | 12.06 | 3.88 | 51.43 | |
| 9 | Ditto | 70 | 10 | 44 | 8.92 | 10.24 | 3.88 | 51.43 | |
| | Mean of 4 experiments = | 67.1 | 7.75 | 44 | 9.82 | 11.36 | 3.72 | 53.75 | |
| 10 | Lackawanna nut anthracite | 106 | 8 | 44 | 8.43 | 9.77 | 5.88 | 34.00 | With blast. |
| 11 | Lackawanna egg anthracite | 108 | 12 | 48 | 10.32 | 11.96 | 6.00 | 33.33 | This series presents some discrepancies in regard to the law that evaporative efficiency follows the inverse rate of rapidity of combustion. But even here it will be seen, that when one pound of coal is burnt in 28.8 seconds, it produced only 10.77 pounds of steam, while the mean of the other six trials, in which the time of burning a pound was from thirty to forty-six seconds, was 11.55 pounds of steam produced. |
| 12 | Ditto | 100 | 12 | 48 | 9.70 | 11.24 | 5.55 | 36.00 | |
| 13 | Ditto | 120 | 10 | 48 | 10.22 | 11.84 | 6.66 | 30.00 | |
| 14 | Ditto | 80⅓ | 12 | 48 | 9.68 | 11.22 | 4.46 | 46.18 | |
| 15 | Ditto | 120 | 10 | 48 | 10.21 | 11.84 | 6.66 | 30.00 | |
| 16 | Ditto | 125 | 12 | 48 | 9.29 | 10.77 | 6.94 | 28.80 | |
| 17 | Ditto | 110 | 18 | 48 | 9.85 | 11.41 | 6.11 | 32.72 | |
| | Mean of 7 experiments = | 109.05 | 12.28 | 48 | 9.89 | 11.55 | 6.05 | 33.86 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 18 | Sydney slack alone.................. | 148⅓.. | 12... | 55 | ....7.50.. | 8.64.. | 8.24.. | 20.23 | Compare this result with No. 1. |
| 19 | Lackawanna egg.................... | 147⅓.. | 12... | 55 | ....9.00.. | 10.28.. | 8.18.. | 24.43 | This result, compared with the mean of Nos. 11 — 17, is less by 12.35 per cent.—due to rapid combustion. |
| 20 | Anthracite dust, three parts—Sydney slack, one part......... | 107... | 13... | 55 | ....9.92.. | 11.37.. | 5.94.. | 33.61 | With blast. |
| 21 | Anthracite dust, half—Sydney slack, half...................... | 112½.. | 12... | 65 | ....9.92.. | 11.13.. | 6.25.. | 32.00 | Compared with the preceding, it appears that a more rapid combustion with this proportion of ingredients gives a slightly diminished evaporation. |
| 22 | Anthracite dust, half—Sydney slack, half...................... | 87½.. | 12... | 65 | ...10.02.. | 11.44.. | 4.86.. | 41.14 | Comparing the mean of these two with Exper. No. 21, we find a gain of 12.49 per cent. by a reduction of one fourth in the rate of combustion. |
| 23 | ...............Ditto............... | 87½.. | 12... | 65 | ...11.91.. | 13.60.. | 4.86.. | 41.14 | |
| | Mean of 2 experiments = | 87½.. | 12... | 65 | ...10.96.. | 12.52.. | 4.86.. | 41.14 | |
| 24 | Philadelphia pea coal, three parts—Sydney fine coal, one part.... | 142... | 9½.. | 75 | ....7.96.. | 9.03.. | 7.88.. | 25.35 | These four experiments stand in the order of the rapidity of combustion, beginning with the highest, and the production of steam per pound of coal will be seen to follow precisely the inverse order. Burnt with blast. |
| 25 | ...............Ditto............... | 1 6... | 12... | 75 | ....9.69.. | 10.96.. | 5.88.. | 33.96 | |
| 26 | ...............Ditto............... | 102... | 12... | 75 | ...10.30.. | 11.67.. | 5.66.. | 35.29 | |
| 27 | ...............Ditto............... | 90... | 11... | 75 | ...10.40.. | 11.78.. | 5.00.. | 40.00 | |
| | Mean of 4 experiments = | 9.33 | 11.66 | 75 | ...10.13.. | 11.48.. | 5.15.. | 36.42 | |
| 28 | Philadelphia pea coal alone........... | 117... | 12... | 75 | ....8.00.. | 9.06.. | 6.5... | 30.77 | |
| 29 | Boston anthracite dust, 3 parts—Sydney slack, one part......... | 83⅓.. | 12... | 44 | ....8.76.. | 10.19.. | 4.63.. | 43.21 | By comparing the mean result of the 29th and 30th experiments with the mean of the 38th and 39th, we find, that by increasing the time of burning a portion of this mixture from 28 to 41 seconds, the evaporation from one pound of coal was increased from 9.33 to 9.81.<br>Experiments 31—34 compared with experiment 10, show that at the same rate of combustion, this mixture is very nearly equal in effect to the nut anthracite of Lackawanna. |
| 30 | ............... Ditto ............... | 91... | 11... | 44 | ....8.10.. | 9.43.. | 5.05.. | 39.56 | |
| 31 | ............... Ditto ............... | 104... | 11½.. | 44 | ....7.60.. | 8.85.. | 5.77.. | 34.61 | |
| 32 | ............... Ditto ............... | 105... | 10... | 48 | ....7.50.. | 8.71.. | 5.83.. | 34.28 | |
| 33 | ............... Ditto ............... | 107... | 13... | 48 | ....9.92.. | 11.50.. | 5.94.. | 33·64 | |
| 34 | ............... Ditto ............... | 110... | 18... | 44 | ....8.43.. | 9.81.. | 6.11.. | 32·72 | |
| 35 | ............... Ditto ............... | 111... | 9... | 44 | ....9.30.. | 10.78.. | 6.16.. | 32.43 | |
| 36 | ............... Ditto ............... | 111½.. | 12... | 48 | ....7.83.. | 9.08.. | 6.19.. | 32.28 | |
| 37 | ............... Ditto ............... | 119... | 18... | 48 | ....7.40.. | 8.60.. | 6.61.. | 30.25 | |
| 38 | ............... Ditto ............... | 127... | 12... | 48 | ....7.84.. | 9.08.. | 7.05.. | 28.34 | |
| 39 | ............... Ditto ............... | 128... | 8... | 48 | ....8.27.. | 9.58.. | 7.11.. | 28.12 | |
| | Mean of 11 experiments = | 108.8. | 12.2. | 45.6 | ....8.27.. | 9.60.. | 6.05.. | 33.59 | |

## TABLE X.—TUBULAR BOILER.

*Tabular view of the evaporative effects of Dr. Dana's Tubular Boiler, formed on the general plan of locomotive boilers. The total length is* 36 *feet; the cylindrical shell* 32 *feet* 6 *inches long and* 33 *inches in diameter; the tubes,* 12 *in number, of the same length as the cylindrical part, and each* 3 *inches in diameter. The grate is* 3 × 3.5 = 10.5 *square feet; the spaces between the grate bars half an inch wide; the interior surface of tubes* 306.3 *square feet, and that of the fire box about* 53.4 *square feet, or the total absorbing surface* 359.4 *square feet. Hence the number of square feet of absorbing surface to one of grate surface is* 34.23.

| No. of Experiments. | Kind of fuel burned. | Number of pounds burned per hour. | Duration of the experiment, in hours. | Temperature of water admitted to the boiler. | Pounds of water evaporated by one pound of coal from the initial temperature. | Pounds of water per pound of coal from 212 degrees. | Pounds of coal burned on one square foot of grate per hour. | Time, in seconds, of burning one pound of coal. | Water evaporated by one square foot of boiler surface per hour from 212°. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Deg's. | | | | | Pounds. | |
| 1 | Lackawanna coarse anthracite. | 79.60 | 12 | 70 | 10.90 | 12.40 | 7.58 | 45.23 | 2.41 | By a comparison of the series here given, we find that the evaporative economy follows nearly the inverse order of rapidity of combustion, and taking the first and sixth together we find a gain of 13.45 per cent. by burning a pound of coarse anthracite in 45 instead of 36 seconds. |
| 2 | ..........Ditto............ | 82.5 | 8 | 34 | 10.60 | 12.42 | 7.85 | 43.63 | 2.43 | |
| 3 | ..........Ditto............ | 83.33 | 12 | 34 | 10.41 | 12.20 | 7.93 | 43.20 | 2.84 | |
| 4 | ..........Ditto............ | 84.16 | 12 | 70 | 10.10 | 11.49 | 8.01 | 42.77 | 2.69 | |
| 5 | ..........Ditto............ | 85.50 | 8 | 34 | 10.52 | 12.32 | 8.14 | 42.10 | 2.92 | |
| 6 | ..........Ditto............ | 10.000 | 9 | 34 | 9.33 | 10.93 | 9.52 | 36.00 | 3.04 | |
| | | 85.85 | 10.116 | 46 | 10.31 | 11.96 | 8.17 | 42.15 | 2.72 | |

It appears from Table X, that when evaporation in the tubular boiler was pushed to 3.01 pounds of water per hour, instead of 2.41 pounds, the loss of total effect of fuel was 13.45 per cent.; but the activity of evaporation or *useful effect of the boiler*, considered solely with a view to the time it was in action, was increased 26.14 per cent. Hence, if the cost of the boiler, per day, including interest, repairs, attendance and incidentals, were equal to that of the fuel it consumed, there might be actual economy in driving it to consume 100 pounds of coal per hour, instead of 80 pounds. Evaporation within any boiler, or on any metallic surface, when the nature and condition of that surface are given, must depend, as was shown in my papers on vaporization, already referred to, entirely on the temperature maintained in the metal, and according to a certain law of increase, will be more or less rapid, as the temperature rises. After reaching a certain point, the rapidity actually diminishes by an increase of heat; but this point is probably seldom reached in ordinary steam boilers — so that with a given pressure, we may take the rate of evaporation in a given boiler to indicate the temperature at which the particular fuel and mode of firing maintain the surface of the iron. When this temperature is kept down in the gaseous products by the entrance of a large quantity of unburnt air, or by the formation, at a low temperature of gases, from the coal, it is evident that the evaporation may remain stationary, though a large increase of combustion may be going on in the furnace.

We are enabled to compare the effect of the tubular boiler of Dr. Dana with the common locomotive boiler used on railroads, through the means of M. de Pambour's careful experiments on those used on the Liverpool and Manchester railway. Thus he found that on an average of eleven experiments with coke, one pound produced from water at 60° Fahr. 6.21 pounds of steam. This is reduced to the standard temperature of 212°, by assuming what has been proved in my experiments on the strength of materials for steam boilers to be the latent heat of the vapor of water, viz.

1030°. Thus the latent and sensible heat imparted to water, of which the initial temperature is 60°, will be 152+1030=1182°, and the quantity of steam generated by any given quantity of combustible from water at 212°, will be $\frac{1182}{1030}$ of what it would be from water at 60°, hence $\frac{11}{1030}\times 6.21=7.126$ pounds, is the weight of water at boiling temperature which would have been converted into steam by this coke. The coke used by Pambour was from a coal yielding 20 per cent. of volatile matter, not useful for evaporative force, and hence the water which would have been evaporated by one pound of the raw coal from 212° is one fifth less than 7.126, viz. 5.701 pounds. In Dr. Dana's tubular boiler the produce is 11.96 pounds of steam per pound of anthracite.

M. Pambour found that in the English locomotive boiler one pound of coke was burned in 6.45 seconds. In Dr. Dana's a pound of anthracite took 42.15 seconds, or more than *six and one half times* as long.

The coke burnt on *each square foot of grate* per hour by Pambour was 79.33 pounds, while in Dr. Dana's experiments it was only 8.17, or a little more than one tenth as much.

The water evaporated by one square foot of surface of boiler per hour by Pambour was 12 pounds, while by Dr. Dana it was only 2.46.

Admitting, as we may probably do with safety, that good coke has nearly the same evaporative power as anthracite, when the two are burned under equally favorable circumstances, it is evident that the slower combustion and longer continuance of gas in contact with the absorbing surfaces of the boiler have given to Dr. D's. result an advantage, in point of economy, of 67.8 per cent.

## TABLE XI.—CORNISH BOILER.

DR. DANA'S *Experiments on Evaporation in a boiler of the form usually employed in Cornwall, being* 36 *feet in length, six feet exterior diameter, with an interior fire-flue three feet ten inches in diameter. Grate placed in the interior flue, two feet two inches above the bottom, three feet ten inches wide and four feet long, containing* 15⅓ *square feet—but after the first experiment, increased to* 23 *square feet. Air passages of the grate half an inch wide. Area of heated surface on the internal flue* 409.4 *square feet, on the four external ones* (144 *feet long*) 630.6 *square feet: total* 1040 *square feet. Whole distance, from the centre of the grate to the entrance of the chimney,* 178 *feet. Made between December* 1839, *and February* 1840.

| No. of Exper. | Kind of Fuel used. | Pounds of coal burnt per hour. | Duration of the experiment. | Temperature of the water on entering the boiler | Pounds of water evaporated by one pound of coal from initial temperature. | Pounds of water from 212° to one pound of coal. | Pounds of coal burnt per square foot of grate, per hour. | Time in seconds, of burning one pound of coal. | Pounds of water evaporated by one square foot of heated surface per hour. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Coarse Lackawanna anthr..... | 70⅓ | hrs.<br>13.5 | 32 | ....7.46 | 8.76 | 4.59 | 51.18 | ....0.592 | This is the mean result of four days' running, reduced to the time of one day. No fan employed at this experiment. Slowest consumption, 55 lbs. per hour. |
| 2 | Grate increased in length to six feet—same coal.. | 153¼ | h'rs.<br>13 | 32 | ....5.35 | 6.28 | 6.38 | 23.48 | ....0.925 | Blast was applied during this trial. Coal put on all at once for the day—2000 lbs. Foggy day. |
| 3 | ...... Ditto ........ | 160 | 12.5 | 32 | ....7.10 | 8.33 | 6.66 | 22.50 | ....1.231 | Coal put on at once for the day; a jet of steam thrown in with the draught, but no fan used. |
| 4 | ...... Ditto ........ | 166⅔ | 15 | 32 | 7.11 | 8.35 | 6.94 | 21.60 | ....1.338 | Fan on. |
| 5 | ...... Ditto ........ | 166⅔ | 12 | 32 | ....6.17 | 7.24 | 6.94 | 21.60 | ....1.160 | Coal put in at once for the day—weather fine—wind N. W. |
| 6 | ...... Ditto ........ | 171 | 11 | 32 | ....7.37 | 8.65 | 7.12 | 21.05 | ....1.422 | No fan; coal charged at intervals, as usual. |
| 7 | ...... Ditto ........ | 200 | 14 | 32 | ....5.65 | 6.63 | 8.33 | 18.00 | ....1.275 | Blast and steam both on. Wind N. W. |
| 8 | Coarse Sydney bituminous coal.. | 233⅓ | 12 | 32 | ....5.40 | 6.34 | 9.72 | 15.42 | ....1.412 | No blast. |
| 9 | Sydney nut coal.... | 233⅓ | 12 | 32 | ....5.37 | 6.30 | 9.72 | 15.42 | ....1.413 | No blast. |

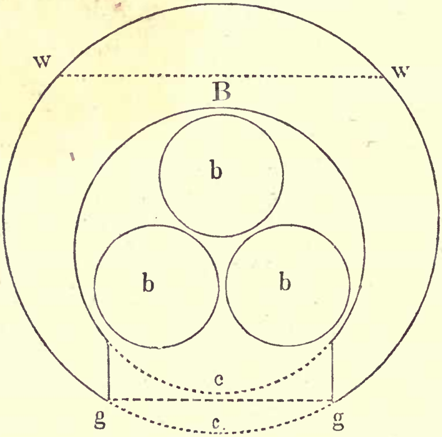
## TABLE XII. — IMPROVED CORNISH BOILER.

*Experiments by* DR. DANA, *on a double cylindrical boiler of the Cornish form,* 36 *feet long, the exterior being six and the interior shell* 3.83 *feet in diameter, into the interior of which were inserted three plain cylindrical boilers each* 36 *feet long and* 19 *inches interior diameter, as represented in the sketch above given. The exterior surface of the three cylinders together, is* 540 *square feet, the interior surface of the* 3 *feet* 10 *inch cylinder* 433.44 *feet, from which deducting the portion cut away to receive the grate* (18 *square feet*), *the remainder is* 415.44 *square feet, and the four exterior flues together give* 630.6 *feet, so that the total heat-absorbing surface of the boiler is* 1586 *feet. Two water-feeding tubes, eight inches in diameter, also ran the whole length of the chamber, giving* 150.4 *square feet of absorbing surface, which added, makes* 1736.4 *feet, used in the first seven experiments.*

| No. of Exper. | Kind of Fuel used. | Number of pounds of coal burned on the whole grate per hour. | Duration of the experiment, in hours. | Temperature of the water on entering the boiler. | Number of pounds of water evaporated by one pound of coal from the initial temperature. | Pounds of water evaporated by one pound of coal from 212 degrees. | Pounds of coal burned on one square foot of grate, per hour. | Time in seconds of burning one pound of coal. | Pounds of water evaporated by one square foot of heated surface per hour. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Beaver Meadow Coal, ordinary size | 116 | 12 | 75 degs. | 11.68 | 13.23 | 6.44 | 31.03 | 0.880 | These two and the five following were all made under a fan blast accompanied by a jet of steam from the boiler. |
| 2 | Ditto | 128 | 9 | 75 " | 12.00 | 13.60 | 7.11 | 28.12 | 1.000 | |
| 3<br>4 | Lackawanna | 138 | 10 | 75 degs. | 12.08 | 13.69 | 7.66 | 26.09 | 1.085 | The difference of 2.41 seconds in burning a pound of coal appears to have made a difference of product of steam to the amount of 1.41 pounds, at 212 degrees, in favor of slow combustion, = 11.28 per cent. |
| — | Ditto | 152 | 10½ | 75 " | 10.84 | 12.28 | 8.44 | 23.68 | 1.070 | |
| 5<br>6 | Pea anthr. 3 parts; bitum. slack, 1 part | 144 | 10½ | 75 degs. | 11.25 | 12.75 | 8.00 | 25.00 | 1.055 | In this series the law with regard to rapidity of combustion would seem to be reversed, but the differences in rate are not probably such as to give positive information, and the discrepancy may be due to the mode of firing. |
| 7 | Ditto | 141 | 12 | 75 " | 10.60 | 12.01 | 7.83 | 25.53 | 0.970 | |
| | Ditto | 125 | 12 | 75 " | 10.14 | 11.48 | 6.94 | 28.80 | 0.825 | |
| 8 | Coarse anthracite, variety uncertain | 117 | 6 | 34 degs. | 9.51 | 11.15 | 6.50 | 30.77 | 0.862 | The mean evaporative result of the first three experiments is 11.32 water at 212 degs. to one coal, when the pound is burned in 26.27 seconds. That of the last three is 10.16 water at 212 degs. to one coal, when a pound is burned in 18.32 seconds. This shows an economy of 11.41 per cent. by increasing the time from 18.32 to 26.27. These results were obtained on six consecutive days. |
| 9 | Ditto | 145 | 10 | 34 " | 9.67 | 11.33 | 8.05 | 24.82 | 1.082 | |
| 10 | Ditto | 155 | 9 | 34 " | 9.76 | 11.47 | 8.61 | 23.22 | 1.156 | |
| 11 | Ditto | 168 | 10 | 34 " | 8.88 | 10.41 | 9.33 | 21.42 | 1.155 | |
| 12 | Ditto | 190 | 10 | 34 " | 9.31 | 10.91 | 10.55 | 19.47 | 1.370 | |
| 13 | Ditto | 255½ | 8 | 34 " | 8.67 | 10.16 | 14.19 | 14.08 | 1.647 | |

The above experiments, from No. 8 to No. 13, inclusive, were made after the two 8 inch water pipes had been removed ; and the inferiority of results points to this as a cause of some importance in obtaining the very high evaporative power, in experiments from 1 to 4 inclusive. In other series by Dr. Dana, the escape heat of the gas flue, not far from the boilers, was made available by passing under the measuring tanks, from which the water passes to the boilers. By this means a temperature of 120° was obtained.

The following sketch represents the general arrangement adopted by Dr. Dana in remodeling his Cornish boiler. The exterior shell, *A*, being six feet in diameter, and the interior one, *B*, 3 feet 10 inches, and both of them 36 feet long ; he removed a portion of the lower arcs at one end, represented by the dotted curves *c c*, to the distance lengthwise of the boiler, of six feet, and in breadth three feet, so as to insert a grate of that breadth, represented by the straight dotted line *g g*. Above this grate, within the inner cylinder, and extending through the whole length of the larger boiler, are placed three cylindrical boilers, *b b b*, each nineteen inches in diameter. From the tops of these are pipes, extending vertically upwards through the inner shell, *B*, of the main boiler, and opening above the level of the water line, *w w*. The three small boilers, *b b b*,



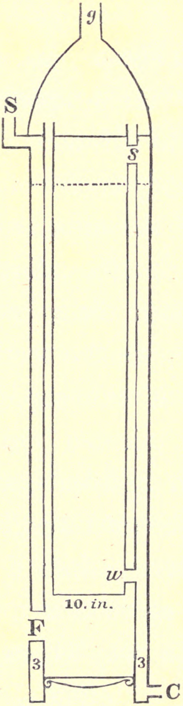
are also connected by suitable water pipes at the ends, both with each other, and with the water chamber of the large boiler, which completely encloses them, except at the ends. Being entirely below water level, they are by these connexions kept constantly filled with water. These interior boilers are suspended, and kept in place by rods coming down from an iron cross beam, resting on the wall of the furnace, beyond the ends of the large shells *A* and *B*.

### *Mr. Francis's Experiments on Vertical Boilers.*

The following results of experiments conducted with great care by Mr. James B. Francis, engineer to the "Locks and Canals Company," at Lowell, has been kindly furnished to the writer by that gentleman. In a double vertical boiler, 12 feet high, 31 inches exterior diameter, 24 1-4 inches interior diameter of the inner cylinder, (leaving, of course, 3 inches between the two); there was placed a single vertical cylindrical boiler, 9 feet 8 inches high and 20 inches in diameter; the bottom of which, therefore, descended to within 2 feet 4 inches of the bottom of the outer shell. Suitable water and steam ways connected this inner boiler with the outer double shell, and a fire door through the latter, afforded access to the grate placed near the bottom of the same. The surface of boiler here exposed to the action of fire, was 126 1-2 square feet; and the area of grate was 3 1-5 square feet; consequently, the boiler surface to each foot of grate surface was 39.$^{5}$ square feet.

In this boiler there was evaporated during a continuous action of nearly five days, between the 22d and 27th of February, 1841, or, more accurately, in 6931 minutes, 54,035 pounds of water by the combustion of 5283 pounds of coarse anthracite, and consequently giving 10.228 pounds of water converted into vapor from 32°, by the combustion of 1 pound of fuel.

This trial was made during the coldest season of the year; the mean morning temperature of the five days was $19\frac{3}{5}$ deg., noon, $29\frac{1}{5}$ deg., and evening 21°. The water supplied to the boiler was constantly at 32°, consequently the total heating power is represented by $\overline{1030 + 180} \times 10.228 = 12{,}376^{\circ}$, which is equivalent to 12.015 pounds of water evaporated from a temperature of 212° by 1 pound of coal. The rate of combustion per hour was 14.3 pounds of coal to each square foot of grate surface, and the water evaporated per square foot of boiler surface per hour was 2.363 pounds. A similar series of experiments, extending from February 15 to February 20, with water also at 32°, gave as the evaporative result 9.16 pounds at the initial temperature, or 11.65 pounds from a temperature of 212°. A slight leak in a part of the apparatus, rendered this result a little uncertain, and it is on the whole less relied on than the preceding. The annexed figure represents a section of Mr. Francis's boiler; *C* is the supply pipe, through which water is injected into the space between the inner and outer cylinders of the double boiler, whence through the water-way, *w*, it finds its passage into the interior single boiler or "pot," as it is termed by the inventor; *s*, is a steam way connecting the upper part of the inner with that of the outer boiler; and *S* is a pipe conducting the steam to the place where it is used in heating the factory buildings. On an enlargement of the same pipe is placed the safety valve; *g*, is a gas pipe, connected with a conical bonnet, through which the products of combustion, escaping through a circle of holes, from the space between the outside of the single and the inside of the double cylinder, are conveyed into the chimney. The pressure was constantly less than 12 pounds per square inch.



## TABLE XIII.—VERTICAL BOILERS.

*Mr. Francis's Experiments were made in two Boilers. Grate surface in each,* 3.21 *square feet. Heated surface in the first two Experiments,* 126.5, *and in the third,* 114.25 *square feet; pressure,* 1 1-2 *to* 12 *pounds.*

| No. of experiment. | Coal burned per hour. | Duration of experiment in hours. | Temperature of water. | Pounds of water evaporated by 1 of coal, from the initial tank. | Pounds of water evaporated by 1 of coal from 212°. | Pounds of coal burned on 1 sq. foot of grate per hour. | Time in seconds of burning 1 pound of coal. | Pounds of water evaporated from 1 square foot of boiler per hour. |
|---|---|---|---|---|---|---|---|---|
| 1 | 22.86 | 112.18 | 32 | 10.245 | 12.03 | 7.13 | 157.48 | 2.74 |
| 2 | 22.80 | 106. | 32 | 9.916 | 11.65 | 7.12 | 157.89 | 2.100 |
| 3 | 40.94 | 317.5 | 32 | 6.68 | 7.857 | 12.75 | 87.93 | 2.815 |

## COMPARATIVE EVAPORATION OF VARIOUS KINDS OF FUEL, FROM WATER, AT 212°.

| | | |
|---|---|---|
| 1. | Wood's trial of coal in a locomotive boiler . . . . . | 7.12 |
| 2. | Pambour's trial of coke in a locomotive boiler . . . . . | 5.12 |
| 3. | Watt's trial of coal, of Newcastle, Albion Mills, Wagon boilers . | 9.63 |
| 4. | Henwood's trial of Welsh coal in Cornish boilers . . . | 11.62 |

| | | |
|---|---|---|
| 5. | Parke's Warwick experiments, bituminous coal | 10.23 |
| 6. | Wagon boiler, mean of eight experiments | 8.76 |
| 7. | Locomotive boiler, coal as fuel | 5.70 |
| 8. | Tredgold marine boiler of the “ African ” Heaton coal | 8.15 |
| 9. | Schaufheautl's trial of anthracite in Player's boiler | 12.40 |
| 10. | Cornish boiler experiment, cited by Henwood | 11.78 |
| 11. | Parkes's and Manby's, on Player's boiler, anthracite maximum | 13.25 |
| 12. | Fyfe's experiment on Scotch coal | 7.74 |
| 13. | “ “ “ Anthracite “ | 10.10 |
| 14. | English bituminous coal Fyfe's open, small, copper boiler | 9.07 |
| 15. | Hayes's experiment on his 4 boilers, 3-4 anthracite, 1-4 bit. dust | 11.83 |
| 16. | Dana's experiments with Beaver Meadow coal, in improved Cornish boiler | 15.56 |
| 17. | Maximum of do. | 16.64 |

At iron works of various kinds, a hot blast is frequently employed. It may therefore be of interest to know what benefit may be derived from its application to the furnace of a steam boiler. To furnish some light on this subject, I make the following abstracts from reports on the comparative economy of the two methods of combustion.

*Extract from Leonard Schwartz's report on the application of hot air to the furnaces of steam boilers.*

[Bulletin de la Societe Industrielle De Mulhausen.]

1. In 1835, an experiment made in the establishment of Andrew Kœchlin & Co. gave for result 1 kilogram of Ronchamp coal, of medium quality; 3.92 k. of steam with cold air, and 5.70 with hot, — gain, 31 per cent.

2. A trial in the boiler of Dollfuls, Meig & Co. One day's work at spinning, with cold air, took 7072 of Gemonval coal; and the same

work was done with 5395 of the same coal, using hot air; — saving 24 per cent.

The furnace which gave 31 per cent. economy with hot air, must have burned the coal very imperfectly, since with the same quality of Ronchamp coal, by repeated trials gave a result of

5.33 steam to 1 coal in a copper boiler,
4.80 " 1 " cast iron boiler,

which shows that nearly as much effect was here obtained by cold air, as at Andrew Kœchlin's with hot air.

## *Experiments in* 1837.

### 1. At Schlumberger, Kœchlin & Co's.

Boiler, 3 lines thick, copper, 20 feet long, 5 feet diameter, with two interior flues, each 15 inches in diameter. The fire goes under the bottom — then returns by the two sides — then passes through the flues to the chimney, which is cylindrical, 100 feet high, 3 feet diameter at bottom and 2 at top. The grate has 20 feet square of surface, and can burn 448 pounds of coal per hour. Two reservoirs of water 30 feet above the boiler, kept up a constant supply by means of a float in the boiler, which keeps the level always the same,

This boiler gave the following result.

### 1. *Cold Air.*

One week day and night — temperature of boiler 350 c.

No. 1, 2000 kilograms of Sarrebruck coal, evaporated 10,000 kilograms of water.

No. 2, 2000 kilograms of Blanzy coal, inferior kind, gave 8000 kilograms of steam.

### 2. *Hot Air.*

No. 3, 2000 kilograms Sarrebruck coal, gave 10,100 kilograms of steam.

No. 4, 2000 kilograms inferior Blanzy coal, gave 8,480.

Hence, there is an advantage of 6 per cent. in favor of hot air.

### 2. At Dollfuls, Meig & Co's.

#### 1. *Cold Air.*

"Boiler, plate iron; 24 horse power; runs under 2 1-2 atmospheres; in 76 hours of work there was consumed 283 hectolitres; 11320 kilograms of Blanzy coal (inferior), being 3.72 half hectolitres, or 148.80 kilograms per hour, of work.

#### 2. *Hot Air.*

"During 78 hours of the same work, 250 hectolitres, or 10,000 kilograms of the same coal were consumed; which gives 3.20 hectolitres, or 128 kilograms per hour. Hence the economy is 14 per cent. In good furnaces, the economy by hot air is less than in such as are badly constructed."

"The hot air flame is shorter than that with cold air; but it is white, more intense, and the fuel is more completely consumed. Bad coal may be used with hot air, when it could not be with cold. Though air must be at 500° centigrade in order to take fire, yet it is evident this heat is more readily attained, when the air comes into the grate at 100° than at 10°.

The hot air principle may always be adopted to advantage, where there is too high a temperature in the gas, escaping at the chimney.

*Extract from M. Ed Kœchlin's experiments on Evaporation, in an apparatus employed in a Dye house. Ronchamp coal.*

1. 18 February, 1827. Air, 15°. Water, 1°. 1 coal produced 7.03. Ashes, 29 per ct.

2. 4 March, 1827. Air, 10°. Water, 7°. 1 coal produced 7.36. Ashes, 16 per cent.

## CONCLUDING REMARKS.

In addition to the evidence furnished by all the above facts in proof of the available heating power of anthracite, it may not be amiss to mention, that at a foundry in Kensington, near Philadelphia, where this fuel is exclusively used, there were melted 204,050 lbs. of iron, by the consumption of 38,600 lbs. of anthracite, or 5.28 lbs. of pig iron melted by each pound of anthracite consumed. There is little doubt that this result is below the maximum efficiency for this purpose.

On reading the preceding accounts of experiments made with anthracite in this country and elsewhere, two circumstances seem particularly worthy of attention; of which the *first* is, that much higher evaporative power has been obtained by means of this fuel, than had ever before been derived from bituminous coal; and the second, that by improved forms or arrangements of boilers, a great economy of combustible of whatever kind can be obtained, over what has heretofore been derived, from that form which prevails in all the iron works, described in these pages.

A beginning has at least been made of some knowledge resting on practical experience, which cannot fail to guide us in our future researches, and to set a due estimate on the rich treasures which Pennsylvania contains within her bosom; and which await but the hand of patient industry to render them available, for establishing our ancient commonwealth on the very pinnacle of prosperity.

*Philadelphia, October*, 1841.

## ERRATA.

Page 16, line 5 from the bottom, for "fact," read *fuel*.
" 116, line 5, for "them," read *steam*.

that this result is below the maximum efficiency for this purpose.

On reading the preceding accounts of experiments made with anthracite in this country and elsewhere two

knowledge resting on practical experience, which cannot fail to guide us in our future researches, and to set a due estimate on the rich treasures which Pennsylvania contains within her bosom; and which await but the hand of patient industry to render them available, for establishing our ancient commonwealth on the very pinnacle of prosperity.

*Philadelphia, October*, 1841.