MOOKHTAR-OOL-MOOLK

Sir Salar Jung Bahadoor G. C. S. I.

ECONOMY OF FUEL,

PARTICULARLY WITH REFERENCE TO

REVERBERATORY FURNACES

FOR

THE MANUFACTURE OF IRON, AND TO STEAM BOILERS

BY

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"In a manufacturing nation such as England, the application of scientific results to the arts, should be the prime object of every employer of skilled labour, who would not be left behind, in the race of improvement."—*Westminster Review*

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SYNOPSIS OF CONTENTS.

APPENDIX.

INTRODUCTION.

1. It would be difficult to exaggerate the importance of the part played by *heat*, both on a grand scale in the laboratory of nature, and on a minor scale, in the domain of human art and science. In the former respect it is not only an essential condition to the existence of life on this planet, but also the prime agent in putting in motion most of the physical changes which take place at the earth's surface. In the latter, it must be regarded not only as furnishing man with the chief means he possesses of imitating in miniature the processes of nature, and moulding and modifying natural productions to his wants; but also as bestowing on him the ability to generate and apply at pleasure, a force equally stupendous and easy of control.

2. Yes, it is to *heat* we are indebted for the aliment which nourishes the sinews of that all powerful giant, yet obedient slave, which the genius of a Watt subdued, and left as a legacy to all succeeding generations. That unwearied drudge of all work, which grinds our corn, weaves our clothing, forges our tools, drives our printing presses, twists a massive cable of iron, or spins a gossamer thread of cotton down, impels our steam ships on their ocean routes, defying wind and wave, or whirls us through space when we journey on land, with thrice the speed of the race horse. A slave more patient than Caliban, fleeter than Ariel, such an one as it never entered into the imaginations of our forefathers in their most sanguine dreams, to hope for the possession of.

3. Nothing furnishes man with greater cause for congratulation and even an excusable pride, than the feats of that mighty impersonation of brute force and human intellect, the steam engine, the Hercules of the nineteenth century, which once launched into the worlds arena, has gone forth "conquering and

to conquer," fulfilling his high destiny as a great civilizing agent, with an energy which no human arm can arrest, and a rapidity which fills us with astonishment, admiration, and hope.

4. For all these achievements man is indebted to the laws which govern the combination of certain electro-positive bodies, such as carbon and hydrogen, with oxygen. It is by carefully studying the laws of the universe, and employing them for his benefit, that he raises himself from the lowest pitch of barbarism, to the height of civilization—from the state of a naked defenceless savage, shivering with cold and hunger, to the well clad, well housed, well fed product of modern civilization, master of an ample supply of the necessaries and comforts of life, with leisure to spare for moral and intellectual cultivation. The same forces of nature, so astonishing and often so destructive to the savage, become, when a knowledge is attained of the circumstances under which they act, the docile assistants,—instead of the rude enemies of man—the allies by whose aid he obtains the mastery over brute matter, employs the elements as couriers, and yokes them to his triumphal car.

5. What is the lesson such a career of progress ought to teach us? at least this,—a wise humility as to the perfection of our present knowledge, and our manufacturing processes founded upon it, diametrically opposed to that narrow-minded conceit of infallibility, and incredulity as to further improvement, which exist in their greatest vigour, just in those narrow arched crania, where ignorance of general principles is the most profound, and incapacity for lifting the mind to imagine a state of things widely differing from the present, the most complete. Just in short, in that class of persons, where this self satisfied state of mind is most misplaced, the most injurious to the interests of the individual, and the most ridiculous in the eyes of others.

6. There are few manufacturing processes that have not been greatly revolutionized, simplified, and extended within these fifty years, and had none but this narrow arched crania race been engaged in them, these improvements would never have been made; for if no one can be found with sufficient knowledge, enterprise, and love of perfection, to be the first to try a new thing, progress becomes impossible. Just the state of things in fact, which exists amongst many nations, whose civilization is stationary or retrograde, and whom we justly look upon as our inferiors—laggards in the race of improvement, whose rank in the scale of

manhood even when industrious, is only that of plodding labourers—the hodmen of humanity—who can no more originate a structure that is new and beautiful, without the inspiration of a superior race, than a bricklayer's labourer can erect, without an architect, the splendid building on which he toils from morn till eve, most praiseworthily employed according to the talent committed to his care, but nevertheless a mere beast of burden, whose task, genius can at pleasure, arrange a few cogs and wheelwork more efficiently to perform.

7. Nations are not generally aware of the extent of their obligation to their leaders, the men who head the career of progress and improvement, fulfilling the part of generals to an army; nor how small a number of such men suffice, where the people are honest and industrious, to redeem the whole body from stagnation, to leaven the inert mass with the inspiration of their own genius, and to impart character, tone, and an object to the national mind, by bestowing its leading ideas.

8. He must be blind indeed, who does not see that ideas rule the world, as absolutely and as necessarily, as the mind the muscles of the body. The whole course of sublunary affairs is in fact but a commentary on the text that "*knowledge is power*," and teaches the entire subjugation of physical, to intellectual force. The former is in reality but the manifestation of the latter, the weapon it employs to execute its volitions, with no independent vitality of its own, but necessarily ceasing to exist with the ideas which called it into life. A fact from which we at least derive the consolation of knowing, that all material interests and brute forces which represent ideas not having truth for their basis, are necessarily doomed to decay, whilst such as are salutary, beneficial, and consequently founded in truth, must eventually prevail and overcome all opposition. The product of the former class of ideas, inherits the seeds of *decay*; those of the second, of *vitality*. How insignificant become in a few years the results of the deeds of a great conqueror. Time would appear to take a pleasure in obliterating with the furrows of his ploughshare every trace of his career; whilst on the other hand, the result of a luminous idea like that of Watt's on the steam engine, essentially prolific in its nature, for ever expands itself as it stretches into the future, giving birth to a numerous progeny of ideas, each in its turn destined to be prolific like its parent, till the imagination loses itself at the vastness of the field of view which opens before it.

9. So low however at present, is the scale of humanity amongst us, that for *one* individual who could be found with open purse and liberal heart, animated with the glorious ambition of aiding in the development of ideas so fraught with great and beneficial results to mankind, as those of Watt; it is to be feared that *one hundred* would be met with, who, deaf to all such considerations, or perhaps even holding them in derision, would reject the opportunity open to them of furthering so good a work, to achieve in preference the grander result ! ! ! of leaving a somewhat heavier money bag to an impatient heir.

10. Let it never be forgotten, that clear, simple, and obviously indubitable, as was the improvement of Watt on the steam engine, requiring, it would be supposed by all (except those who have had practical experience of the *vis inertia* of ignorance,) only to be seen, to be adopted with acclamation, yet it was eight years before he succeeded in getting any one to try it, and had not a fortunate chance at that period introduced him to a liberal, enlightened, and enterprising man in Boulton, another eight years of fruitless efforts might have had to have been undergone, or even the full appreciation of the invention indefinitely delayed. In which case, the whole of that vast career of progress on which the human race entered as a consequence of the steam engine, would have been postponed; the issue of the great European war might have been different; colonies rapidly increasing in wealth and importance, would have remained desert wastes; large cities now flourishing, would have been unbuilt, and millions now living, unborn. How little and pitiful beside a Boulton, appear the men who devoid of all love of perfection, hug themselves with secret self-complacency on their superior wisdom, in leaving to others the risk of making a first experiment, reserving to themselves the more gainful part of appropriating the discoveries revealed and established by the researches and experiments of their contemporaries. ' Glorying in what constitutes their disgrace, they form the drones of the hive, who contribute nothing to the common fund, but exist by the labours of others. Strangers to the honest pride of being the creditors, rather than the debtors of society, and receiving nothing from it for which they do not return an ample equivalent.

11. Numerous as are the inventions for which society stands indebted to the fertile genius of Watt, his first, that of the condensation of steam in a vessel separate from the cylinder, transcends all others in importance. For half a century after

the introduction of the steam engine, the mode of forming the vacuum beneath the piston, was by conducting the condensing process in the cylinder itself, and the cooling down of this vessel necessarily resulting from this operation, was productive of an enormous waste of fuel, entailing as it did, the necessity of re-heating it to its previous temperature upon the readmission of steam, a process performed by the first portion of the entering steam at the expense of its own condensation. Such was the loss of time and heat consequent upon this bungling arrangement, that when Watt solved the problem of *condensing the steam without cooling the cylinder*, by having recourse to what now appears to us the *obvious* expedient of employing a separate condensing vessel, he increased at one bound the efficacy of the steam engine 75 per cent. Now if I am not greatly mistaken, at the present day, with regard to the management of some kinds of furnaces, practices prevail, scarcely less productive of waste, than the old plan of cooling down and re-heating the cylinder at every stroke, was, with reference to the steam engine.

12. Considering the importance of the question of furnace management, and the amount of capital involved in it, I am struck with surprise at the little aid it has hitherto derived from science. There is scarcely a process in manufacture in which heat is not one of the prime agents employed, so that it may without exaggeration be stated, that *the question of consumption of firing, lies at the root of the cost of production.* Has then anything like the amount of intellect been devoted to the examination of this subject of economy of fuel, which the magnitude of the interests involved in it, and its importance in a national point of view, render it deserving of? Are the processes and appliances we have recourse to, the result of careful deductions, made from a searching and scientific consideration of the question from an elevated point of view, untrammelled by those narrow notions which daily routine too frequently engenders—or rather, have not methods and systems, which originated at a period of comparative darkness in physical science, been continued from habit down to the present day, without adequate reflection and research? Methods in fact, which gradually developed themselves as necessity dictated, to the untutored intellect of uncultivated men; and which, however creditable to our forefathers who devised them, inasmuch as they availed themselves of all the sources of infor-

mation within their reach, are nevertheless a reproach to the more advanced knowledge of physical, chemical, and mechanical science, enjoyed by the present generation.

13. So paralizing with most persons seems to be the effect of habit and routine upon the intellect, in checking all original ideas with regard to operations it has from childhood been daily accustomed to see performed in a certain manner—so entirely in such cases does the *mode*, become identified with the *result*, that the power of independent reasoning on the subject appears to be lost. It is a notorious fact, that most of the greatest improvements in arts and manufactures, have been achieved by individuals not educated to the calling; the illustrious Watt, for example, was bred a mathematical instrument maker, Arkwright a barber, and Stevenson with his iron steed, emerged from the depths of a coal mine. Conversing on this topic lately with an engineer of celebrity, he related in corroboration of the sentiments I expressed, that a highly intelligent friend of his, who had been very successful in business as a manufacturer, declared that when practicable, he always made it a rule in his establishment to select for the superintendants of the different processes, individuals of intelligence who had not been brought up in that department, giving as a reason, that if there was any improvement to be made, they were ten times more likely to discover it, than a man who had become a mere unreasoning creature of habit.

14. To produce rapid combustion and intense heat in a furnace, it is necessary for the fuel to be rapidly supplied with air. A current of air must in fact, be kept constantly rushing through it, a desideratum which may be effected in two ways, either by allowing the products of combustion to pass into the chimney, at a sufficiently high temperature to produce by their rarefaction a partial vacuum adequate to cause the requisite current of air through the fuel by atmospheric pressure, or by compressing the air by some *mechanical appliance*, and forcing it through. Thus *sucking* the air through the fuel in the first instance, and *blowing* it through in the latter; producing the current in one case by a partial *vacuum behind*, in the other by a *compression before*, the fuel.

15. Now however compatible with the objects sought to be attained, and allowable as a question of economy, may be the plan of keeping up the draft through a fire, solely by the instrumentality of a chimney, where *slow* combustion only is required,

as in the case of the domestic grate, or the Cornish steam boiler; whenever on the contrary, rapid combustion and intense heat are a desideratum, such a system can only be carried out, and the air discharged by the chimney at a temperature sufficiently high to produce the powerful draught required, by an enormous sacrifice of fuel. It is true that an inordinately high chimney, by lowering the temperature at which it is necessary to keep the ascending column of air, may palliate the evil, but as a question of economy the remedy is almost as bad as the disease, besides being in very many cases, as in marine engines, and locomotives for example, inadmissible from other causes.

16. I shall no doubt excite general surprise, and perhaps some incredulity, when I state that from a calculation I entered into on the subject (the result of which certainly surprised myself), I find that 1 lb. of coal expended through the mechanical agency of a steam engine, will generate more force, and consequently is capable of producing a stronger current of air, than 500 lbs. of coal expended in heating a column of air to act by its diminished specific gravity, through a chimney 35 feet high; and that consequently, all the products of combustion which are allowed to escape out of the furnace into the chimney, before they have fallen below the temperature at which they can be usefully employed,—*for the sake of producing draught*,—are most prodigally misapplied.

17. Strange to say however, this is the system at present almost universally employed, apparently in utter unconsciousness of its wastefulness, and notwithstanding the fact, that numerous collateral advantages are attendant on the employment of compressed air, not the least of which are the perfect control it gives over the action of the furnace, and the extent to which it enables us to utilise the escaping heat. All that can be said in behalf of the present system, is, that it possesses a certain rude simplicity and easiness of application, qualities which might be equally urged in favour of a pair of bellows compared with a blast cylinder, or of panniers and pack-saddles compared with wheel carriages.

18. The result of the employment of this wasteful and unscientific system, is seen in the fact, that in steam engines where an intense draught is employed, the consumption of fuel is 25 per cent. more than that of those where the products of combustion are reduced to a comparatively low temperature before they enter the stack. In fact, unless working with compressed air

be resorted to, we cannot have *multum in parvo* in a steam engine —*great power in little space*, without great waste of heat. To burn a large quantity of fuel in a small area, we must have a rapid rush of air through the furnace,—to produce a rapid rush of air through the furnace, we must have a powerful draught in the stack,—to attain a powerful draught in the stack, we must discharge the products of combustion into the stack at a high temperature,— and to discharge the products of combustion into the stack at a high temperature, necessarily entails an enormous waste of fuel—the actual, though very unsatisfactory result at present. Enclosed in a vicious circle, each step in the process is necessary and inevitable, as long as so erroneous a path is pursued, and there is no avenue of escape, but by having recourse to a blowing machine, and producing the required current of air, with $\frac{1}{500}$ part the fuel at present wasted in the chimney, in effecting less efficiently the same object.

19. In no case is the wasteful result of trusting solely to draught in the *stack*, to create draught through the *fuel*, more striking, than in furnaces for the manufacture of iron. Here, from the iron lying at the bottom of the furnace out of the axis of the line of draught, and the impossibility of causing the heat to circulate round it as in a steam boiler, only a small fractional part of the heat generated, enters the iron. In fact it is impossible to be otherwise, as the stack, acting the part of a suction pump through an orifice 1½ foot in area, empties the furnace of its gaseous contents *twice in a second*, keeping up at the same time a state of exhaustion, which draws in cold atmospheric air at every crack and cranny, and particularly in puddling furnaces at the working hole; oxydising and wasting, or, as the workmen say, *cutting* the iron. In the principal axis of the draught, the products of combustion dart in a straight course from fire bridge to flue bridge, at the rate of 30 feet per second, and can, as a matter of course, leave but a small portion of their heat behind them. If we contrast with such a state of things, that of a furnace *distended* with heat impelled by pressure from behind, and struggling to escape in all directions faster than a *comparatively* contracted neck will allow of, and suffering moreover no cold air to enter, it will be easily seen with which system the superiority lies.

20. Injudicious as the method of working furnaces on which I have animadverted must appear to my readers, yet they are I suspect, scarcely prepared to learn the actual results:

viz:, that in a melting furnace, the amount of fuel consumed, is adequate to produce twelve times as much heat, as would if all absorbed by the metal, raise its temperature from 60° to the melting point; whilst in puddling furnaces the disproportion is still greater, the heat generated being, if the fuel employed be taken as an index, 16 fold more, than can be contained in the metal during any period of the operation.

21. Now I am not so visionary as to suppose that a furnace can be constructed so as to make all the heat generated enter the iron. It is impossible to isolate the body of heat contained in a furnace and prevent its loss by radiation, and where processes requiring intense heat are carried on, from the necessity that exists for keeping up a rapid supply of fresh heat to replenish this loss, and enable the requisite temperature to be maintained, discharging also at the same time from the other end of the furnace, the *slightly cooled,* though *still intensely hot* gaseous products—the consumption of fuel must ever be very great, in proportion to the actual amount of heat taken up. In short, we must never lose sight of the fact, that the quantity of *available* heat generated for any process, has no relation to the *whole* quantity generated, but is merely the amount of the *excess* of the temperature produced, above the temperature required. Fully weighing these considerations however, I am nevertheless still sanguine enough to believe, that the results obtained in the puddling, and heating furnaces, may be effected with a great diminution in the quantity of fuel now consumed; and notwithstanding it ever must be necessary in order to keep up the requisite heat in the body of iron furnaces, to discharge the products of combustion whilst still at a very high temperature, yet at the same time, there is nothing to prevent our economising this heat, by applying it to various purposes for which its temperature, though no longer equal to the manufacture of iron, is amply sufficient.

22. This introduces us to the subject of the difference between *quantity* and *quality* or *intensity* of heat, through losing sight of which, many errors have been committed, and various chimerical attempts made to economize this agent. For since we possess no means of *condensing* it, an *unlimited quantity* becomes valueless for any purpose requiring a higher temperature than it is capable of furnishing. Were not this the case, our steam engines when once set in action, might be kept

at work for ever, without any further expenditure of fuel than would suffice to replace the trifling amount of heat lost by radiation from the surface of the machinery, since we get back in the condenser, the heat we bestow in the boiler. The heat we impart to a cubic inch of water, to raise it into a cubic foot of steam, being returned to us when the atmospheric temperature is 50°, in the shape of 24 cubic inches of water at 100°, *virtually* representing a power capable of raising 1 ton weight a foot high, though *practically* we can make no use of it, unless we can discover some employment for it, for which a temperature of 100° suffices.

23. The preceding observations must have made it apparent, that processes of manufacture requiring intense heat, and where, as a necessary corollary, the products of combustion must be discharged at a high temperature, can never be economically conducted, unless some employment be found for the waste heat so discharged. In an iron work, none can exist more advantageous and convenient than the generation of steam for the machinery employed,—for which object, strange to say, at the present moment, separate furnaces and fires are extensively employed, in the midst of dozens of puddling and heating furnaces, each briskly engaged in dissipating into the atmosphere, heat sufficient to generate steam for an engine of 20-horse power.

24. A vast field for economy is here open, by the introduction of the *system of working with compressed air*; for without this invaluable assistant, our power to employ the waste heat is limited to a comparatively narrow compass, inasmuch as precisely in the ratio that our arrangements for this purpose become more perfect, do we destroy the draught of the furnace. By the employment of compressed air however to furnish a current for the supply of our fires—and by this means *only*—do we possess the power of using the waste heat at pleasure, however high may be the temperature demanded, and, as a consequence, keen the draught through the fuel required.

25. An opinion that much unnecessary waste of heat takes place at present, and that there is scope for great saving, seems to exist almost universally as a sort of obscure impression, without sufficient knowledge of the subject being possessed, to know where, and how, the saving is to be effected; and in groping in the dark to achieve this object, great errors are often committed, of which we have recently had a notable example, in the

various attempts that have been made to puddle iron with the gases that escape from the top of the blast furnace.

26. Now, it is not surprising that persons who understand nothing of the principles of physics and chemistry involved in the right management of a furnace, should be incapable of appreciating a system, based on correct data, when presented to them. Accordingly, in the few opportunities I have enjoyed of conversing on furnace management with those whose interests ought to have made them best acquainted with the subject, I have met with nothing but a strange confusion of ideas, and a deplorable ignorance. When for instance, I have attempted to discuss the question of working with compressed air, with a view to elicit their opinions, I have discovered that the parties I addressed, were deficient in that ground-work of knowledge, necessary for the appreciation of scientific facts and arguments, and without which, appeals to the reasoning faculties are fruitless.

27. I confess, I did at the outset, delude myself so far as to suppose, that the notorious fact—that furnaces work better with a breeze blowing into the ash-pit, and also when the barometer is *high*, than when it is *low*—would have secured a favorable opinion on behalf of a proposal for merely further carrying out these conditions, and making them *constant* by *artificial* means. Even with those whose knowledge did not enable them to see very deeply into the matter, the analogy was, I thought, too obvious to be overlooked: observation has taught me however, that where the mind possesses no fixed scientific principles for its guidance, every process is surrounded with mystery, and every proposal for change invested with doubt. Incapable of separating the *accidental* from the *necessary*, no *à priori* convictions are possible.

28. Deeply impressed with the belief, that it would be difficult to over-estimate the beneficial effects which would arise, from the general diffusion amongst the practical men who carry on our manufacturing processes, of a knowledge in outline of the scientific principles involved in the various operations they conduct, I have determined to contribute my mite towards realizing such a result.

29. In carrying out this intention, it has been my especial aim to condense the largest possible amount of information into the smallest possible compass, and to express what I had to say,

in the clearest and most familiar language. Such a compendium would at one period have been most thankfully welcomed by myself: in fact, it was experiencing the want of such an one, that caused me to make for my own satisfaction, those inquiries, the result of which I here present for the benefit of others. The absence of a compendium of the kind, has, I have reason to know, long been felt and regretted in manufacturing districts; and I trust and believe, that the present imperfect attempt partially to remedy the deficiency, will not prove entirely useless.

ERRATUM.

Page 4.—7th line from bottom, for 967·26 lbs. × 181·5, read 967·26 ÷ 161·5

ON

ECONOMY OF FUEL.

GENERAL CONSIDERATIONS.

1. The subject of Economy of Fuel appears at first sight to resolve itself into,—firstly, the attainment of perfect combustion; and secondly, the application of the heat thus obtained, so as to make the largest portion available for the object to which it is devoted.

2. A closer scrutiny however, shews that practically speaking, it comprises two other departments, which by no means yield to the former in commercial importance, viz.: contrivances for the employment of inferior kinds of fuel, and methods for turning to account the refuse heat, which, having fallen below the temperature required for the particular process carried on, is yet available for other processes for which a lower heat suffices.

3. In getting the better kinds of coal a large quantity of an inferior description is at the same time obtained (technically denominated slack), in some cases its inferiority having reference solely to the mechanical attribute of *size*, in others comprising also a slight difference in *structure* and chemical *composition*, with perhaps the admixture of a certain portion of earthy matter. When it is considered that at present this article has so little commercial value, as in the majority of cases, to be totally wasted and not deemed worth removal, it becomes evident that any method by which it can be made to do the duty of ordinary coal

is valuable, even should the quantity consumed be greatly in excess of that demanded of the latter; and though a method for ensuring more perfect combustion, and thus effecting a saving of perhaps 20 per cent. in weight of fuel, is of priceless value where steam navigation is concerned, and the fuel constitutes *ex necessitate* a portion of the freight,—and such an achievement would be doubtless fraught with much greater interest to the man of science than a scheme for burning slack,—it is nevertheless unquestionable that a rough and ready method of accomplishing this latter object, even with a large expenditure of the material, presents, in many cases, greater attractions in a commercial point of view.

4. To appreciate the value to be expected from the use of judicious means for applying waste heat, it should be known, that so high is the temperature required in various stages of the manufacture of iron, that a stream of ignited gases is required to be kept constantly rushing through the body of the furnaces, the whole atmospheres of which are renewed in many cases twice in a second. The current of heated gases however issuing from such furnaces is still of an intensely high temperature, from 2,500° to 2,800°, and although not sufficient for the manufacture of iron, which demands a temperature of 3,000° and upwards, is fully equivalent for working tin, lead, or zinc, the melting points of which are respectively 442°, 612°, and 773°, whilst that of cast iron is 2,786°. Even after having done serviceable duty in fusing these metals, it would still retain a temperature adequate for raising steam, soap-boiling, and various other industrial operations; and there really exists no reason whatever why as much duty as possible should not be extracted from it before its final dismissal into the atmosphere. In short, this department of Economy of Fuel is a very fertile one, though hitherto so all but entirely neglected, that it might be supposed that fuel, like air, was an article inexhaustible in supply, and costing nothing to procure, instead of demanding for its attainment the wear and tear of human sinews, and the risk of human life.

SECTION I.

ON THE BEST MEANS OF RENDERING COMBUSTION PERFECT.

5. COMBUSTION is, strictly speaking, the development of heat by *chemical combination*, but though this may take place from the union of a variety of bodies, the omnipresent agent oxygen plays so vastly more important a *rôle* than all others in the disengagement of light and heat, that the act of its combination with other bodies is preeminently entitled *combustion*, and except in the mouths of chemists, has quite monopolised the appellation. Since combustion, in the *ordinary* acceptation of the word, is the only means had recourse to in the arts for the development of artificial heat, *perfect combustion* may, for our purpose, be defined to be—the combination of a combustible body with the largest measure of oxygen with which it is capable of uniting. In fact, for all practical purposes, the fuel or combustible body employed may be regarded as composed exclusively of carbon and hydrogen, so that our enquiry becomes narrowed to the combinations of oxygen with these two elementary substances.

6. Most of my readers are doubtless aware that chemical combinations take place only in certain definite proportions which are multiples of each other. One atom of A, for instance, combines with one, two, three or more atoms of B; or two of A, with three, five, or more of B; from which fact it follows, as a necessary consequence, that the chemical equivalents (or combining weights) of all bodies may be considered as expressing the relative weight of their atoms. Bodies may be *mingled* together in any proportions, but it is only in certain definite ones that they unite and form one homogeneous whole. Thus six parts (by weight) of carbon combine with eight (by weight) of oxygen to form carbonic oxide, and with twice this quantity, or sixteen parts, to form carbonic acid; and there exists no intermediate combination of

these two bodies in which six of carbon is united with more than eight, and less than sixteen of oxygen. Carbonic oxide and carbonic acid gases may, it is true, be *mingled* in any proportion, and thus a gas obtained in which six parts of carbon are present with more than eight, and less than sixteen parts of oxygen, but this is a *mixture* and not a chemical *unity*, as may be shewn by the addition of potash, which will separate the carbonic acid and leave the carbonic oxide behind.

7. Different coals vary much in their component parts, and in the proportion of these to each other; carbon and hydrogen however, are the essential ingredients of all, as far as their heating capabilities are concerned, and throughout this essay, I shall assume as a convenient standard, that 100 parts of coal consist of 80 parts of carbon, and 5 of hydrogen, leaving out of view the other elementary substances which enter into their composition, (consisting of oxygen, nitrogen, sulphur, and incombustible ashes in various proportions,) as only likely to complicate the details, without being essential to the argument.

8. Assuming 100lbs. of coal to consist of 80lbs. of carbon and 5lbs. of hydrogen, then, since the oxygen is to the carbon, in carbonic acid, as 16 to 6, to effect perfect combustion, 80lbs. of carbon will require 213⅓lbs.=2,527 cubic feet of oxygen, to furnish which, 967·26lbs.=12,635 cubic feet of atmospheric air will be required, air consisting of 1 volume of oxygen to 4 of nitrogen, or 8 parts by weight of the former, to 28 parts of the latter; and since oxygen is to hydrogen, in water, as 8 to 1, 5lbs. of hydrogen will require 40lbs. = 473 cubic feet of oxygen, or 181·5lbs = 2,365 cubic feet of atmospheric air.

967·26lbs. × 181·5 = 1148·76lbs. = 15,000 cubic feet of atmospheric air, required for the perfect combustion of 100lbs. of coal.

And the product resulting will be: 2,527 cubic feet of carbonic acid, 946 cubic feet of steam, and 12,000 cubic feet of uncombined nitrogen.

9. We thus perceive that each 1lb. of coal requires 150 cubic

feet of air for its perfect combustion, or, in other words, for the conversion of all its carbon into carbonic acid, and all its hydrogen into water; and it must be remembered, that just in proportion as this proper quantity is *deficient*, is combustion imperfect and fuel wasted, whilst the supply of a *surplus* quantity is but a change of evils, and equally injurious in an economic point of view, since all the air which passes through a furnace without giving up its oxygen to the fuel, serves only to abstract heat, without yielding any in return. However difficult may be the regulation of the admission of just the proper quantity of air to the fuel, it is not the less certain, that exactly in proportion as we deviate from the correct standard, will be the loss we incur, for the laws of chemical affinity are unerring and inexorable.

10. It is commonly but erroneously supposed, that when no smoke appears at the chimney top, combustion is perfect. Smoke, however, may be absent, and yet the carbon may only have united with 1 atom of oxygen, forming carbonic oxide, (a colourless gas), instead of with 2 atoms, forming carbonic acid, and consequently have only performed half* the duty, as a fuel,

* I have said *half* from a desire rather to understate than overstate the argument, but *two-fifths* is probably a near approximation to the truth. There is no doubt, but that the combination of the second atom of oxygen with carbon, *sets free* more caloric than that of the first, since, in the first combination, a considerable portion of heat must necessarily be swallowed up and become latent, to produce the gasification of the carbon, and experiment confirms what might *à priori* have been expected.

The figures in the following columns show how many parts of water are heated 1° by the combustion of 1 part of carbon, according to the three observers, Dulong, Andrews, and Grassi.

	D.	A.	G.
1 part of carbon in becoming CO^2 . . .	13267·8	14220	13885·2
1 part of carbon as CO in becoming CO^2	10569·6	10209·6	7786·8
1 part of carbon in becoming CO	2698·2	4010·4	6098·4

It thus appears that if the whole heat generated by the combination of 1 atom of carbon with 2 atoms of oxygen forming CO^2, be regarded as a unit, the *proportional* quantity developed by the combination of the carbon with the first atom of oxygen, will be, according to Dulong, only 20 per cent., according to Andrews, 28 per cent., and according to Grassi, 43 per cent.

[Dulong's

of which it was capable, whilst the loss of duty on the coal taken as a whole (supposing all its hydrogen to have become oxydised) will be upwards of 40 per cent.

11. Hydrogen, having a stronger affinity than carbon in the gaseous state, for oxygen, when the supply is short, still seizes on its equivalent, and leaves the carbon minus. Thus, when coal gas (carburetted hydrogen) is inflamed with an insufficient supply of air to effect the perfect combustion of both its constituents, the hydrogen is still converted into water, whilst the carbon, in different proportions according to the oxygen present, becomes—deposited in the form of soot—converted into carbonic oxide,—or partly into carbonic oxide and partly into carbonic acid.

12. This great cardinal point in economy of furnace management, viz. the exact apportionment of the supply of air to the wants of the fuel, so as to convert all its carbon into carbonic acid, and all its hydrogen into water, could be achieved with comparative ease were the same conditions always present in the interior of the furnace, so as to cause the quantity of air required by the fuel to be *uniform*. In this case, the average rarefaction in the stack being once attained, a steady supply would enter the furnace according to the area of the grate bar openings, the size of which once adjusted, the equable and economic working of the furnace would be secured. Unfortunately however the reverse is the case, and the great practical difficulty to be overcome in apportioning the supply of air to the demands of the fuel, arises from the fact, that in furnaces of the ordinary construction,

Dulong's figures are manifestly erroneous. That four times (!) as much heat should be developed by the combination of carbon with the *second* atom of oxygen, as by its combination with the *first*, is so discordant with everything we know of the principles of chemistry, as to be quite incredible. Dulong however, has unfortunately been the authority followed by Professor Bunsen and Dr. Lyon Playfair, in their report on Blast Furnaces (see *Report of the British Association* for 1845), and there is no doubt but that great deductions require to be made from their statements in consequence.

this demand is not only *variable*, but fluctuates within very wide limits.

13. Where a fresh supply of coal is put on a briskly-burning fire, the first thing which takes place is, that the coal softens and swells, attended with the evolution of a large quantity of carburetted hydrogen gas, requiring for its combustion a correspondingly large supply* of atmospheric air—the coal undergoing, in fact, in the first stage of combustion, just the same process as it does in the retort in the manufacture of gas, but with this difference in the result: that the gas, which in the latter case is preserved and found so valuable a commodity, here escapes unconsumed up the chimney, not only furnishing no heat itself, but abstracting from the heat arising from the combustion of the carbonaceous portion of the fuel, the heat for its own gasifaction,—a circumstance which readily explains the fact, that more heat is practically obtained in many kinds of furnaces from coke (or in other words, coal deprived of ⅓ part by weight of that portion of its combustible matter which is richest in furnishing material for heat,) than from coal in its pure state, with all its hydrogenous portion intact. From the same cause also (viz. the imperfection of our furnaces), the commercial value of coal is often in the inverse ratio to the quantity of its bituminous constituents and its real heat-giving powers, had we the capacity to render them practically available. It could not in fact be otherwise. A furnace immediately after a fresh supply of fuel, requires more than double the quantity of air it did the instant before, whilst we have no contrivance for furnishing such a supply, although without it, throughout the space of time during which rapid gasifaction of the hydrogenous portion is going on, more than half the fuel consumed is wasted, and passes off unburnt, becoming thereby not only totally unproductive in itself, but absolutely an agent of evil, by robbing the furnace of the heat absorbed in its own volatilization.

* 1 measure of carburetted hydrogen or coal gas, requires for its perfect combustion 10 measures of air.

14. Whether it be from an inadequate appreciation of the magnitude of the evil, or from the difficulties attendant upon overcoming it, I will not determine; but certain it is, that 99 furnaces out of 100, are worked without any attempt being made at a remedy. Large quantities of coals are thrown over brightly-glowing cinders, the heat from which they absorb; a rapid evolution of gas takes place, which, passing off unburnt at a comparatively low temperature, most injuriously cools down the heat of the furnace and flues, and by lessening the amount of rarefaction in the stack, enfeebles the draught, and thus still further diminishes the already insufficient supply of air, and reproduces the original evil in an aggravated form. In furnaces so managed, for the first two or three minutes after coaling, the useful effect of the furnace is comparatively paralyzed, and the process in which it is employed partially suspended; and it is only gradually that it regains its full vigour of action.

15. Only two methods present themselves by which the supply of air and the wants of the furnace can be made to correspond,—*either both must be made constant and regular*, or *the fluctuations of one, must be made to coincide with those of the other.*

16. If a continuous and equable supply of air is to be furnished to a furnace, then, in order that this supply of air may exactly correspond with its requirements, the supply of fuel must be made continuous and equable also; so that at all times there shall be just the same quantity of fuel in the same state, that is to say, at the same stage of combustion. „This appears to be the most perfect method of working a furnace, and the most obvious mode of overcoming the difficulty, and it is accordingly to accomplish this object, that most of the attempts to prevent smoke and attain perfect combustion have been hitherto directed. Brunton's revolving grate, Juckes' endless chain of fire bars, and more than one kind of rotating feeder, all fulfil with tolerable efficiency the purposes for which they were designed; but the great drawback is, that unfortunately all require machinery and

motive power constantly at work to keep them in action, whilst some are in addition unhandy, and others expensive, both to construct and keep in repair.

17. The result of none being free from these objectionable qualities is, that none have been able to force their way into use to any extent, 99 furnaces out of every 100 at the present moment, being fired by the rough and ready method of throwing the coals on by hand, without any contrivance being resorted to, to mitigate the evils resulting from the inadequacy of the supply of air, to the wants of the fire at the periods of coaling.

18. Fully recognizing the force of those objections to the present contrivances which have prevented their coming into use, and impressed with the belief that no plan of the sort will ever force its way, that does not come recommended by much greater simplicity;—in seeking a remedy for existing evils, it has been my aim to adapt myself to present usages, and devise some method by which the supply of air and the wants of the fuel may be mutually adjusted, without either serious innovation on established arrangements, demand for motive power, or costly apparatus.

19. The contrivance by which, without infringing either of these conditions, I propose to achieve the great desideratum sought, effects its object by admitting an increased supply of air at the periods of coaling, thus acting on the principle of causing the *fluctuations between the supply and demand to coincide*, without undertaking the more formidable, and I think superfluous task, of adjusting the one to the other, by *making both uniform* and *unvarying*—a feat hitherto only accomplished at the sacrifice of simplicity.

20. Whatever opinions may be entertained as to the general merits of my contrivance, it is I think impossible to deny that it has the recommendation of great simplicity, and presents in this particular a striking contrast to those at present before the public. *All the existing arrangements for coaling remain uninterfered with.* The stoker, when he closes the furnace door after

firing, will raise the arm of a lever appended to it; this movement throws wide open a sliding valve in the face of the door, which immediately commences closing slowly and automatically, by the gravity of the lever, regulated and restrained by the motion of a balance wheel connected with it by appropriate gearing, and affords, during the progress of its descent, a *gradually diminishing* supply of air to the fire, in harmony with the *gradually diminishing* requirements of the fuel. The area of the valve, and the period of time throughout which the act of closing is to be prolonged, are of course questions of detail to be determined by circumstances, and should be so adjusted according to the nature of the coal, and the average quantity supplied at one time, as entirely to prevent the appearance of smoke. The door of the furnace should be double, and the air should pass into the furnace through a series of perforations in the inner plate. By this arrangement three important points are secured: 1stly, the heating of the air; 2ndly, its subdivisison into minute jets; and 3rdly, the keeping of the outer surface of the furnace door comparatively cool, and thereby both economising heat, and preventing its radiation outwardly to the annoyance of the attendants.

21. An attempt is often made by careful stokers to mitigate the smoke and imperfect combustion, arising from the inadequacy of the supply of air to the wants of the fuel at the periods of coaling, by leaving the furnace door ajar for a certain period after the addition of fresh fuel. The great superiority of a valve self closing, and with a gradually diminishing aperture, over such an imperfect expedient, is too obvious to be contested. Not only does the air, in the former plan, enter *en masse* and cold, instead of in small jets and hot, but the means of gradually and regularly lessening the supply, according as the gasifaction of the bituminous portion of the fuel becomes completed, is totally wanting; whilst, should the closing of the door be forgotten, and thus delayed till after the completion of gasifaction, more harm will probably be done by the air entering during the latter

portion of the time, than the amount of good achieved by the portion which entered previously. In short, one method requires superintendence to effect imperfectly, what the other accomplishes much better without any, and both superiority of effect, and easiness of application, are found united in favour of the method of adjusting the supply of air by means of an automatically-closing valve.

22. In ordinary furnaces, the air becomes heated in passing through the grate bars and burning fuel. Where air is suffered to enter the furnace above the fuel, too much stress cannot be laid upon the necessity for either supplying it *hot*, or making a provision for subjecting it, together with the volatile products of the fuel, to an adequate amount of heat before they are allowed to escape by the flues: otherwise a mass of cold air, mingling with the gases arising from the fuel, may reduce the temperature of the mixture below the point at which its inflammation is insured, and the gases consequently pass off unburnt, though provided with the requisite supply of air. This is peculiarly the case in steam boiler furnaces, where the gases issuing from the fuel are liable to be chilled by coming in contact with the boiler plate, which, having water on the other side, is consequently preserved at a low temperature, whilst being metallic, and consequently a good conductor of heat, its refrigerating action is rapid and powerful. In this circumstance will be found an explanation of the fact, that little practical benefit is to be derived from leaving the door of steam boiler furnaces ajar for a certain period after coaling. The fuel unquestionably demands a larger supply of air at this period, but this air being admitted *en masse*, and cold, and the heat of the furnace having been just previously lowered by the refrigerating effect of the fresh supply of coals and sudden development of gas, at the expense of the stock of heat previously existing, the result is, that the temperature produced by the union of the cold air with the gases from the fuel, is below the point required for inflammation.

23. In reverberatory furnaces for the manufacture of iron, on

the contrary, the gases arising from the fuel in the grate, have to pass through the *intensely heated body, or working chamber of the furnace* in their way to the stack; and this cavity, which may be said to be an oven with the sides and roof at a white heat, although having another office, becomes in reality a provision for subjecting the gases and the air with which they are mingled to an adequate amount of heat, to insure their inflammation; and the result is, that if an adequate *quantity* of air be admitted, whether cold or hot, all the combustible matter is consumed, and smoke entirely prevented.

24. Many times have I stood before such a furnace just after a fresh supply of coals has been added, with my hand on the open door, and found that by regulating the width at which I kept it open, I could exercise a perfect control over the action of the furnace. If closely shut, a dense black smoke would issue from the chimney; if opened a very little, the smoke would be slightly but perceptibly diminished; if opened a little more, the change would be denoted by a still further diminution of smoke; whilst an opening of a certain extent would cause the smoke to cease altogether. As the process of gasifaction progressed, and the demands of the fuel for air became less, the same effect would follow from a smaller and smaller orifice, till at length the door might be closed altogether without smoke resulting, the ordinary supply of air through the grate bar openings being adequate to the current demands of the fire.

25. In furnaces of this description, beyond all doubt a self-closing valve, which should perform automatically, what I effected by watching and close supervision, would be a valuable acquisition and tend greatly to economy, whilst nothing can be more easy and simple than its application.

26. A consideration of the phenomena exhibited by reverberatory furnaces has led me to the conviction, that a very great improvement might be effected in the action of steam boiler furnaces, particularly those of marine boilers, by coating the under side of the boiler plate, where it forms the roof of the furnace,

with a thin layer of fire-brick material, which, instead of cooling the mingled stream of coal gas and atmospheric air below the point of inflammation, as is now done by the iron surface of the boiler, would contribute heat, if necessary, to assist in kindling them. The sheathing of fire-brick should extend from the surface of the fuel on one side, over the roof of the furnace, to the surface of the fuel on the other side, and closely in apposition with the boiler plate, by which means its melting or rapid burning away will be prevented.

27. Such an arrangement would not only be productive of great economy of fuel by the more perfect combustion which would be attained, but would likewise tend very materially to preserve the supply of steam constant and regular—a point of great value; whilst at the same time the durability of the boiler would be much increased by its being withdrawn from those sudden alternations of temperature to which it is now exposed, and which practice has shown to be so injurious to its stability.

28. Considering the powerful refrigerative effect exercised on the furnace by the addition of a fresh charge of coal, where, as is now the case, a large quantity of the gases generated by the rapid absorption of the previous heat of the furnace are allowed to pass off unburnt, (thus robbing the furnace of the heat required for their volatilization, and yielding none in return,) and therefore how greatly the heat to which the boiler is subjected, is diminished on such occasions, I am of opinion that the whole amount of heat imparted to the boiler surface in contact with the fire-brick, would equal that which it obtains from the direct action of the fire under the present system; and if so, since the heat imparted to the flues behind it would be unquestionably greater, the capacity of the boiler for generating steam would be increased. To turn however the access of heat obtained by the more perfect combustion to the best account, an increase should be made in the heating surface of the boiler, the simplest and best way of doing which, is by inserting a few water-tubes in the main flue behind the fire-bridge: so placed, they act as stays to

the boiler, and are at the same time most advantageously situated for the generation of steam.

29. There is nothing mysterious, unintelligible, or recondite in the views here developed on the subject of furnaces; on the contrary, their general accuracy will be universally admitted, whilst the simplicity of the remedies proposed, constitutes in the opinion of the writer, their chief claim to attention. For reverberatory furnaces, the automatically-closing valve is complete in itself; but for steam boilers, though the valve is useful alone, to reap the full measure of the benefit it is capable of conferring, it should be conjoined with the fire-brick sheathing, and some increase of heating surface, as before recommended. With these adjuncts to its utility, I feel assured that the economy resulting from its use would be great and decided, particularly with regard to the furnaces of marine engines, which, as at present constructed, present great scope for improvement.

30. Some method for economising fuel for the purposes of ocean steam navigation may be said to be the great want of the day, for this vast and rapidly increasing means of transit, is at present fettered in its development, and shorn of half its utility and advantages, by the necessity which exists for loading the vessels with coal, to an extent which leaves but little room for profitable cargo. A writer in one of our periodicals lately declared, that "the man who should achieve a great reduction in the consumption of fuel in marine engines, would deserve, not only the largest fortune and general thanks of mankind, but the gratitude of the latest posterity;" nor will this view of the importance of the subject appear exaggerated, when it is considered,—that for every ton of coals dispensed with, a ton of freight may be substituted—the cost of the former saved, and the price of the latter gained; that several Ocean Steam Navigation Companies are in existence, to whom a saving in the consumption of fuel, to the extent of only ten per cent., would be equivalent to an annual saving of £50,000; and that, concomitantly with the attainment of *increased economy in the cost of*

conducting these great undertakings, the existing obstacle to a reduction in the fare for the conveyance of passengers would be removed, and an impetus given to our intercourse with the most remote corners of the globe, the bearing of which on the future destinies of the human race it would be difficult to estimate.

SECTION II.

ON CONTRIVANCES FOR THE EMPLOYMENT OF INFERIOR KINDS OF FUEL.

31. In getting the better kinds of coal, as has been already observed, a large quantity of an inferior description is at the same time obtained (technically denominated slack), in some cases its inferiority having reference solely to the mechanical attribute of *size*, in others comprising also a slight difference in *structure* and chemical *composition*, with perhaps the admixture of an extra portion of earthy matter.

32. In entering upon the question of the employment of inferior kinds of fuel, it is advantageous clearly to discriminate between what is possible, and what is impossible, between what can, and what can not, be effected. By so doing, will abortive schemes, with the disappointment attending them, be best prevented. It is *not* then possible, even by the most ingenious contrivances, to generate heat from the alumina and silex present in considerable quantities, in the more inferior descriptions of slack. Neither can such earthy matter be dissipated and consumed, nor prevented from remaining as a vitreous residuum on the grate bars, and choking up the furnace unless removed. It *is* however possible to make slack perform all the duty of good coal, where its inferiority has reference solely to its deficiency of

size,—and this is accomplishing a great deal; since, for want of knowing how to effect this object, thousands of tons of it are now annually abandoned as valueless. Something more however than this may be effected; for, if its proportion of earthy matter be not too excessive, good service may be got out of it by means of the appliances which I shall describe, even for processes where, without their assistance, small coal of the best quality would be found insufficient.

33. We should however always carefully distinguish between inferiority resulting from mere *smallness of size,* and that depending upon the presence of an undue portion of *earthy matter,* since, without keeping this distinction in view, no clear ideas can be entertained on the subject of slack burning. If, by superior furnace arrangements, we enable slack, even when alloyed with 25 per cent. of earthy matter above the average of good coal, to do the ordinary duty of the latter, it will nevertheless be found that ¾ of the weight of pure coal *in the same improved description of furnace,* would do the same work with still greater facility. In fact, it is evident that the utmost point to which human ingenuity can arrive, is to burn all the combustible matter any sample of coal may contain, and the less percentage of this present, the greater *weight* of coal required for a given amount of work. Notwithstanding the visionary expectations which have been indulged in on the subject, to expect more, is an hallucination that could not enter into the mind of any one grounded in even the first principles of chemistry.

34. The principal use to which the better descriptions of slack are now applied, is the generation of steam in the steam boilers, used in the manufacturing processes carried on in the locality where it is raised. This channel is, however, quite inadequate for the consumption of the quantity found in getting the immense supply of good coal demanded for our great iron works.

35. Many attempts have been made to substitute slack, or even a mixture of slack and coal, for best coal in the manufacture of iron; but in the ordinary reverberatory furnace this

cannot be done, without a diminution in the activity of the combustion and the intensity of the heat generated, entailing a delay in the process, prejudicial to the yield of iron. And when it is considered that 1 cwt. of iron is of about the same value as 1 ton of coals, it will readily be perceived that no profit is to be derived by economising the latter at the expense of the former.

36. The desideratum required is evidently a furnace furnished with some contrivance, by means of which the combustion of slack can be so stimulated and quickened, as to vie in vigour and intensity with the combustion of best coal in the ordinary furnace.

37. The great difficulty in the way of attaining rapid combustion and intense heat from slack, even of the best quality, arises from the fact that its small size makes it lie so close together, as to form a mass almost impervious to air, and overlying and closing the grate bar openings, the passage of air into the furnace is in great measure cut off.

38. The remedies for this difficulty are, either the admission of air through *orifices in the sides of the furnace*, to compensate for the diminished quantity which enters through the grate bars, or the attainment of the same object by the use of *compressed air in a closed ash-pit.*

39. Many circumstances induce me to give the preference to the latter plan, independently of any partiality I may be supposed to entertain towards it as its originator. To the former however must be conceded the advantage of requiring no collateral assistance in the shape of a machine for compressing air, &c.; and where the slack is of good quality, that is to say, not too small, and containing but a moderate proportion of earthy matter, this furnace will do its work very efficiently, provided the flues for heating the air entering at the sides be judiciously constructed, and proper means be employed to keep the orifices from becoming stopped up by the melted scoria or slag, which forms from the vitrifaction of the sand and clay contained in the fuel, and adheres to the sides of the furnace.

40. The first furnaces of the kind that were constructed, failed from this cause. The ingress of the air at the sides being arrested through the blocking up of the perforations by melted slag, and no efficient contrivance for keeping them clear suggesting itself to the mind of the experimenter, strange to say, the plan was abandoned without any effort being made to overcome the difficulty.

41. It being represented to me that the failure arose solely from an inferior fire-brick having been used for building the sides of the furnace, the melting and running of which had sealed up the orifices, and that all that was necessary to the success of the scheme was the employment of fire-brick of a better quality, I was induced to try the experiment. The plan adopted, originated with a Mr. Cond, and its principle was the supplying the furnace with air (previously heated in a flue or chamber) through small orifices in the sides of the grate. The only deviation I made from the original design, consisted in changing the source from which the supply of air for the air chamber was drawn, by which a great obstacle to the successful working of the furnace was removed, and a higher temperature at the same time secured to the air entering the sides.

42. The first time I entered an iron work, I was struck with the enormous quantity of heat escaping to waste in all directions, to the annoyance of the workmen. Upon closer inspection, I found there were various draft holes leading to the space beneath the iron bottom of puddling furnaces, for the express purpose of allowing the air to circulate freely, and carry off the heat from the iron bottom plates with sufficient rapidity to prevent their melting; whilst conjointly with this arrangement I saw that the fire grates of these same furnaces were fed with a supply of cold air from the atmosphere. My first attempt to partially remedy this waste was by constructing flues beneath the bottom plates, so arranged as to convey the air, heated by passing over the surface of these plates and through the bridges, into the side flues for the supply of the air chamber of the improved furnace,

instead of allowing these flues to draw their supply direct from the atmosphere, as had previously been done.

43. The result achieved by this furnace worked with ordinary coal was a saving of 17½ per cent. in weight of fuel, not as compared with the *average* consumption, but when matched against the *best* furnace in a work containing about forty. These furnaces are constantly at work night and day, from Monday morning to Saturday night, so that it is only once a week that an opportunity for inspecting the interior occurs. On getting inside the grate of the furnace after its first week's work, I found that the small orifices round the sides communicating with the air chamber were either partially or entirely sealed up, by the melting and running of the face of the bricks, and also by the adhesion of the clinkers or slag. This had occurred, notwithstanding the best Stourbridge bricks had been employed, and I saw at once I had been led into an error, in being taught to believe that all the furnace required to complete its efficiency was a good quality of fire-brick; for it was clear, that even supposing a perfectly infusible brick could be obtained, the melted scoria from the fuel alone, would suffice to choke up the perforations, and consequently, that unless some method could be adopted for cleaning them from time to time, the plan was a failure.

44. As it was evident that a large proportion of these holes had been more or less completely stopped up during the latter part of the week, I came to the conclusion that a portion of the saving should be attributed to the less amount of heat lost by radiation into the atmosphere from the sides of the furnace, owing to the circumstance of its being surrounded by a bad conductor of heat in the air chamber. Could I then unite this saving in fuel, from the smaller amount of radiation, with the still further increase that might be expected from more perfect combustion if I succeeded in keeping the holes from the air chamber into the grate permanently open, there was room to hope that a great addition might be made to the economy already effected.

45. Whilst inspecting the interior of the furnace, it occurred to me that this object might be attained, by having suitable openings in the external wall of the furnace, leading into the air chamber, by means of which a tool might be passed through the orifices in the internal wall of the air chamber, into the fire, once or twice a day, for the purpose of cleaning; * such openings at other times being kept closed by doors, so as to prevent the entrance of cold air; and I accordingly lost no time in carrying out my ideas, but erected a furnace on these principles. Its success was complete, and though eventually abandoned from the opposition of the workmen, who set their faces against it the moment they found it was to be applied to burning an inferior description of coal, which they considered inimical to their interests, it is nevertheless unquestionably a great step in advance of any furnace previously employed in the iron trade, and must ultimately, unless interfered with by some further improvement, force its way into use.

46. This further improvement is however, in my opinion, to be found in the system of working with compressed air in the ash-pit. In this powerful mode of stimulating combustion, we have precisely the desideratum required to overcome the difficulties which the tardy passage of the air through small coal

* In the first furnace which I constructed with these cleaning openings, with a view to prevent the men destroying the brick-work of the side of the grate, in passing the cleaning bar through the perforations, I had an iron plate cast, with perforations in it corresponding to those in the brick-work, to serve as a guide for the cleaning tool. In order to gain space for the air chamber, and at the same time to confine the exterior of the furnace as far as possible within its former dimensions, it was found necessary to build the side of the grate of only 2½in. brick-work, the iron plate being relied upon to give the requisite strength. After being in use a short time, a considerable portion of one of the sides fell down, leaving the iron plate intact. To my surprise, instead of melting, it stood alone, and proved as efficient and durable as the other parts of the grate. Acting on the hint, I have since repeatedly made use of iron as a material for grate sides, where these are required with perforations, as more durable than brick-work, which is apt to be damaged by the passage of the cleaning tool.

throws in the way of eliciting from slack the rapid combustion and intense heat required in many manufacturing processes. The power of control possessed by the workman over the action of his fire is greater than that bestowed by any other system, and the increased efficiency of the furnace, in every point of view, compensates ten-fold for the additional apparatus required. An engine of 10-horse power is amply sufficient to compress the air for twenty furnaces, being at the rate of half-a-horse power per furnace, and since there is a superabundance of waste heat, no expense is incurred for fuel, but the whole outlay is limited to the first cost of the machinery and the keeping it in repair.

47. The money saving effected by the substitution of slack for coal is just one half; coal in Staffordshire being worth 5s., and the best slack 2s. 6d. per ton. The quantity consumed in the puddling furnace is about 16 tons per week, so that the cost of the weekly consumption would be, with coal £4; with slack, £2; or, speaking in round numbers, the entire substitution of slack for coal would save £100 per annum per furnace, and the use of a mixture of equal parts of slack and best coal, would be attended with a saving of £50 per annum per furnace.

SECTION III.

ON THE USE OF COMPRESSED AIR, IN REVERBERATORY FURNACES.

48. With regard to the plan of working furnaces *with compressed air in closed ash-pits*, believing it destined to play a very important part in furnace management, I shall give a brief narrative of the steps by which I was led to a perception of its advantages. According to my ideas, its use will not be restricted to the burning of small coal, though this alone would give it a

very extensive field of operations, but will extend to its general employment, as an adjunct to rarefaction in the stack, for furnishing the force required for producing the rapid rush of air through a fire, necessary for rapid combustion and intense and concentrated heat. By means of its assistance, the power required may be obtained at a much cheaper rate than by trusting entirely to rarefaction in the stack, which only produces a powerful draught, at the expense of discharging the products of combustion at a proportionally high temperature.

49. Although a great saving had been effected by the furnace with perforated sides, with the improvement of cleaning doors for keeping the perforations open, far from resting contented with what had been already accomplished, I regarded it rather as an earnest of future advances; and my notions of the state of perfection that ought to be attained were particularly dissatisfied with the fact, that whilst a great quantity of heat escaped to waste, the principal supply of air entered under the ash-pit bars *cold*. As there was ample waste heat for the purpose, why should not the *whole* supply of air furnished to the fire be previously heated?

50. Whenever I took any steps to effect this object in the puddling furnace however, I encountered the fact, that precisely as my arrangements for heating the air became more perfect, did I destroy the draught through the fuel, deaden the fire, and lessen the yield of iron. This unexpected result I attributed to the rarefaction of the air in the ash-pit. When the atmosphere is at 60°, air is doubled in volume at 568°, a temperature below what is practically attained by causing it to circulate in contact with the heated bottom and sides of a puddling furnace. When thus rarified, a much smaller quantity will pass in a given time, under the ordinary pressure of the atmosphere through the interstices of the fire-bars, than would pass were the air at 60°, and consequently of double the density, and the result is a greatly diminished draught, and less intense combustion; and it is to not having rightly appreciated these conditions, that the numer-

ous failures which have been incurred in attempting to apply heated air to furnaces, must in part be attributed.

51. In puddling furnaces, the body or working chamber of the furnace, where the operation of iron making is carried on, and through which the products of combustion rush in their path to the stack, is freely open to the atmosphere at the working hole, and it is the air with its full compliment of oxygen which enters at this aperture, which is principally instrumental in oxydising and wasting, or, as the workmen say, cutting the iron: the air which has passed through the fire having yielded its measure of this gas to the fuel. When therefore we supply the ash-pit exclusively with air which is expanded to double its volume by heat, whilst on the one hand we have a greatly diminished weight of air entering the fire through the bars, and a less intense combustion, we have on the other hand the usual quantity, that is to say, under the new state of things, *double* the *proportionate* quantity of cold oxydising air entering at the working hole, and hence the waste and poor yield of iron.

52. The desideratum in puddling, is to have so free a draught through the fire, as *to keep the body of the furnace full of flame*, and prevent as much as possible the indraught of cold unde-oxydised air, through the working hole. A certain amount of exhaustion being created in the body of the furnace by the action of the stack, it is clear, that just in proportion as the products of combustion rushing from the grate are slow in supplying this void, will the quantity of cold air that enters through the working hole be increased.

53. That the quantity of air passing by the working hole, should form an influential element in the result attained, will not excite surprise, if we examine what this quantity may amount to, and how greatly it may vary. The application of a pressure gauge to the stack of a puddling furnace, shows a vacuum equal to ·24 of an inch of water, or a pressure of ·2 of an ounce per square inch, at which pressure the theoretical rate of influx is 39 feet per second, and consequently, supposing the size of the

working hole to be 4 in. by 4 in., or 16 square inches, this would allow of 260 cubic feet of cold air entering the furnace per minute. Deducting 25 per cent. for friction, would still leave nearly 200 cubic feet as the quantity practically entering. The average quantity will however fluctuate greatly, as the relative pressure of the atmosphere acting through the grate bars or through the working hole, varies with varying currents of air.

54. I thus arrived at a clear perception, that to give the system of supplying the fuel with hot air the fullest development of which it was capable, it would be necessary to supply this air to the fire *under pressure;* but whether the benefits accruing would so greatly outweigh the expense and trouble of the additional appliances necessary, as to render its adoption advantageous in a pecuniary point of view I was not prepared to say.

55. It was not fated however that I should remain long in doubt: I had yet to witness the operation of puddling in a gale of wind blowing in the direction of the working hole. Being in an iron work one squally day, my attention was arrested by a volume of oaths from one of the puddlers, whose furnace, being situated at the extremity of a rank, was particularly exposed to the wind, which blew directly into his working hole. With two large pieces of sheet iron suspended behind him, in the vain hope of warding off his adversary, he was labouring away in a state of great exasperation, and apparently to but little purpose. The dull red colour of the iron showed the deficiency in temperature, and it was with difficulty it could be made to cohere into a mass. When the more violent gusts of wind came, so great was the quantity that entered the furnace, and so completely did it destroy the draught, that puffs of smoke were forced out at the ash-pit.

56. The workman himself was in much too ill a humour for conversation, but another puddler who was standing by, observing the interest with which I watched the proceedings, addressed me, saying, "You see, sir, how very badly this furnace works; the man can hardly make his iron at all. Well now, if the wind should

change in the course of the day, and a nice steady breeze set into the ash-pit, this furnace will work as well as any furnace on the works; and this man's partner who comes on to-night, will do his work with comfort in two hours less time, and perhaps make 1 cwt. more iron."

57. Now it immediately occurred to me that if the *accident* of the wind's blowing into the ash-pit made such a difference, the same difference ought to be created *artificially*, and made *constant*, and concomitantly with this idea, I recognized the fact, that with the immense quantity of waste heat escaping by the stack, no fuel would be required for a steam engine to compress the air, and that therefore the expense of the system would be restricted to providing the machinery, and keeping it in repair.

58. The more I reflected on the subject, the more I became convinced that whilst we were dependent upon the caprice of the wind for the working of our furnaces, we were in fact in a state of barbarism; and though such extreme cases as the one I have just related might not be very frequent, yet lesser fluctuations must be constantly taking place with every change of the barometer, making in the course of the year, a large aggregate amount of loss from bad working. Indeed, that perhaps a more exact view of the case would be, to regard our furnaces as being constantly kept at work at a point of efficiency, far below what a little contrivance would enable them to reach.

59. Led as I had been by another path, and for another object, to contemplate the alternative of having recourse to the employment of *compressed air*, the subject had of course for me a peculiar interest, and I determined forthwith to examine it in all its details. The result of this examination was, that the further I proceeded with my task, the more agreeably was I surprised to find how completely, with many advantages peculiarly its own, it remedied the *defects* and supplied the *wants* of the present system; and I soon became impressed with the firm conviction, that it formed the only route by which we could ever

hope to attain to a satisfactory point of perfection in furnaces where a powerful draught and intense heat are required.

60. To produce rapid combustion and an intense heat, requires a rapid current of air. The essence of the present system of furnace management, is to procure the power necessary for forcing or rather sucking this supply of air through the fuel, from the levity (=heat) of the ascending column of gases in the stack. That there are many defects in such a system is obvious. In the first place, the power of stimulating the combustion, being dependent upon the combustion itself, the capability of independent control is wanting, and energetic combustion can never be otherwise than gradually attained. Thus after fresh lighting, it takes four or five hours to bring the puddling, heating, and melting furnaces used for iron, to a working heat. Not only so however, but precisely at the moment when from opposing causes you require to spur on the action of the furnace, not only does such a power fail you, but the energy of the furnace languishes, from the very cause which rendered a stimulus desirable. You get a reaction, but one in the wrong direction, and which allows the original evil to be reproduced in increased intensity. For instance, in the case of the puddler I have alluded to, the working of whose furnace was so much impaired by the wind blowing into his working hole, it would have been desirable to have removed the ill effect as quickly as possible, and lessened its power of recurring in the same intensity, by increasing the pressure of air in the ash-pit, and the fierceness of the combustion; but what actually took place, was, that the amount of cold air which entered the furnace at the working hole, reduced the temperature of the ascending column in the stack, and entailed, as a necessary consequence, a diminished draught of air through the fire, and an enfeebled combustion, just when the contrary condition of things was most urgently needed.

61. In working with compressed air, on the contrary, the action of the furnace *is always under direct control*, and can be heightened or diminished at pleasure, and in such a case as the

one just referred to, by turning on an adequate current of air, the power of the wind acting in the adverse direction might be defied, and none of it allowed to enter the furnace; with the result of a saving of iron, of fuel, of labour, and of time. Indeed, in the manufacture of iron, the saving in the latter ingredient always entails that of the three former, and is of all others, the most certain channel by which their economy can be attained.

62. Another advantage attendant upon a diminution of the time occupied in manufacturing processes is, that a smaller number of furnaces will turn out a given quantity of work, thus diminishing the amount of capital employed, and the expense of repairs.

63. The desideratum being to keep the atmosphere of the body of the furnace at a given intensity, with the least expenditure of fuel, it will not be difficult to show that the plan of doing so solely by *exhaustion*, by sucking as it were the heated gases from the fire rapidly through the furnace into the stack, is essentially defective; that under no point of view can it sustain, except at a disadvantage, a comparison with the contrary system of using compressed air as an aid to rarefaction in the stack, for promoting draught.

64. In one case we have the furnace *distended* with flame struggling to escape, and only discharged as it becomes forced out by the pressure of the volume of flame behind it; whilst a pressure being maintained above that of the atmosphere, no draught of cold air can enter the furnace, either through the work-hole or any accidental fissure, to lower its temperature, or oxydize its contents. In the other case, on the contrary, the exhaustion operating through the neck, has a constant tendency to empty the furnace of flame, and, at the same time, to suck in cold air directly from the atmosphere through every available aperture, to the lowering of its temperature, and the injury of its contents. The very conditions on which the draught through the fire depends, necessitate a facile egress for the products of com-

bustion because an independent power is wanting, to overcome the friction of forcing them through a more contracted orifice, the resistance, eddies, and commingling of gaseous currents, occasioned by which process, are so instrumental in making them yield up their heat to the parietes of the furnace, instead of carrying it into the stack. The larger the neck, the larger the axis of draught, and the larger the quantity of gaseous matter which darts in a straight line through the centre of the furnace, leaving little of its heat behind it, and imperfectly performing its duty.

65. Where an opportunity exists for substituting slack for best coal, by means of taking advantage of the stimulating influence of compressed air on combustion, the benefit in an economic point of view attending the use of air under pressure (amounting to a saving of half) is of course so great and decided as not to admit of dispute. I have endeavoured however to show that it has more general and universal claims on our attention, than that of being merely regarded as an admirable instrument for slack burning, great, though these unquestionably are: in short, I wish to recommend it for general employment, as an adjunct to rarefaction in the stack, whenever powerful draught is required; maintaining that the combined use of the two, offers a cheaper means of obtaining the force required, than trusting solely to the latter; and that whenever heat which might be otherwise beneficially employed, is dismissed into the stack for the *sake* of heightening the temperature, and consequently the draught, it is sadly misapplied, inasmuch as the hundredth part of it employed in raising steam to be applied mechanically, would be productive of a greater effect.

66. Before entering into any calculation on the subject, I *felt* that the having recourse to the comparatively inert power of gravity (through the ascending power of a column of heated air,) must be a wasteful mode of obtaining the force requisite for producing the necessary draught of air through the fuel, when compared with the expedient of generating the same force, by the

vastly more energetic power developed by the chemical law of vaporisation, (upon the addition of heat to a liquid,) as in the case of converting water into steam. I was not however prepared for the actual results which presented themselves, viz:—that 1lb. of coals employed to raise steam, and applied in a steam engine, will do the work of 500lbs. expended in rarefying air, such air acting through a height of 35 feet, the elevation of the stack of a puddling furnace.

67. The force of the draught in a stack or chimney, is the *preponderance* in weight of a column of air of the area and height of the stack, and of the temperature of the atmosphere, over the column of rarified air with which the stack is filled.

68. Now, since the air at 60° expands $\frac{1}{508}$ for every degree of heat imparted to it, when the atmospheric temperature is 60° (n), the number of degrees the air is raised in the stack above the external atmosphere, multiplied by (h) the height of the stack, and divided by 508, $\left(\frac{n \times h}{508}\right)$ will equal the height of a column of *rarefied air*, equivalent in weight to the deficiency in the stack, and $\frac{n \times h}{508 \times n} =$ the height of a column of air at the *atmospheric density* equivalent to the above. The rate of efflux, is the velocity a heavy body would acquire in falling this height, to find which, multiply the square root of the height of the fall, by 8, or in practice, to allow for friction, by 6.

69. One part of carbon, will raise 14,220 parts of water 1°, and if we estimate the specific heat of air at ·25, that of water being 1, then 14,220 × 4 = 56,880 parts of air raised 1° by 1 part of carbon.

70. Now, since the heating power of hydrogen is to that of carbon as 60,854 to 14,220, or about four-fold, if we estimate coal as composed of 80 parts of carbon, and five of hydrogen in the 100 parts, the 5 parts of hydrogen being about equivalent to 20 parts of carbon, we may calculate the heating power of coal to be weight for weight, the same as carbon.

71. Now the stack of a puddling furnace is 35 feet high, and we will assume the temperature of the ascending column of rarefied air to be 2,600°,—an estimate above the truth.

72. Supposing then that 1lb. of coal will raise 56,880lbs. of air 1°, it will raise 22·3lbs. 2,540°, and 2,540° + 60° for the temperature of the atmosphere = 2,600°, the estimated temperature of the ascending column of rarefied air in the stack.

73. Since air at 60° increases in bulk $\frac{1}{508}$ for every degree of heat imparted, at 2,600° its volume is increased six-fold, and the difference in weight between a column of air weighing 22·3lbs. at 2,600°, and a column the same size at 60°, will be 111·5lbs., and 111·5 × 35, the height of the stack, = 3,902·5lbs., the lifting force capable of being exerted through the space of a foot by 1lb of coal employed in rarifying air, such air being transmitted through a stack 35 feet high; and supposing no loss to take place by friction, eddies, and progressive loss of temperature in the ascent. Deduct for these, the odd 902·5lbs., or 23 per cent., and we get lifting force exerted by 1lb. coals employed in rarefying air, such rarefied air being discharged through a shaft 35 feet high, = 3,000lbs. raised 1 foot. Now in some of the Cornish engines, the duty performed by 1lb of coals is 500-fold the above, = 1,500,000lbs. raised 1 foot; or in other words, 1lb. of coals employed to raise steam, will do the work of 500lbs. expended in rarefying air, such air being discharged through a stack 35 feet in height.

74. The above calculation clearly shows that it is a sad misapplication of heat, to employ it in generating power through the ascending force of a column of heated air, and consequently, that whatever heat might be economically employed in other ways, is most prodigally wasted, when allowed to escape by the stack for the *sake* of draught,—a tolerably decisive fact in favour of the superiority of the system of ventilating coal mines by mechanical agency, as proposed by Mr. Brunton, over the old method of rarefying the air in a shaft by a fire at the bottom.

75. The best instrument for compressing the air for furnaces,

where only a slight condensation is required, as in reverberatory furnaces and steam boilers, is a fan. Though theoretically making but a small return for the power expended, it is practically the most convenient, and half-a-horse power is sufficient for a puddling or mill furnace. And for such furnaces, the whole expense of employing the system of working with compressed air, is restricted to the cost of the machinery, since no expenditure will be incurred for fuel. On the contrary, the result of the adoption of the plan, is greatly to increase the quantity of available heat. Under the present system, heat sufficient to generate steam for about 5-horse power, is as much as can be substracted from the flue of a puddling furnace, without injuriously affecting the draught; the flues of 4 furnaces being applied to a 20-horse boiler. By the assistance of compressed air however, double this quantity may be taken with safety, so that the extra quantity rendered available by its application to one furnace, would suffice to furnish power to compress the air for ten.

TABLE

Of the Temperature in Stacks of different heights, necessary to produce a given Pressure.—External air at 60°.

Pressure in water. Inches.	Pressure in air. Feet.	Weight on sq. foot in lbs.	Weight on sq. in. in $\frac{1}{100}$ oz.	Theoretical rate of efflux in feet per sec.	Temperature in stack 34½ feet high. Deg. Fah	Temperature in stack 69 feet high. Deg Fah.	Temperature in stack 138 feet high. Deg Fah.	Temperature in stack 276 feet high. Deg Fah
2	138	10·564	116	94	...	...	...	568*
$1\frac{19}{20}$	134·55	10·2999	113·1	92.8	...	...	...	543·22
$1\frac{18}{20}$	131·1	10·0358	110·2	91·6	...	...	...	519·61
$1\frac{17}{20}$	127·65	9·7717	107·3	90·4	...	...	...	497·11
$1\frac{16}{20}$	124·2	9·5076	104·4	89·2	...	...	4632*	475·63
$1\frac{15}{20}$	120·75	9·2435	101·5	88	...	...	3616	455·11
$1\frac{14}{20}$	117·3	8·9794	98·6	86·6	...	...	2938·66	435·47
$1\frac{13}{20}$	113·85	8·7153	95·7	85	...	...	2154·85	416·68
$1\frac{12}{20}$	110·4	8·4512	92·8	84	...	...	2092*	398 66
$1\frac{11}{20}$	106 95	8 1871	89·9	82·75	...	...	1809 77	381 38
$1\frac{10}{20}$	103·5	7 923	87	81·4	...	...	1584*	364·8
$1\frac{9}{20}$	100·05	7·6589	84·1	80	..	...	1406	348 86
$1\frac{8}{20}$	96 6	7·3948	81·2	78.6	...	...	1245·33	333·53
$1\frac{7}{20}$	93·15	7·1307	78 3	77·2	...	...	1115	318 8
$1\frac{6}{20}$	89·7	6·8666	75·4	75·7	...	...	1003·42	304·59
$1\frac{5}{20}$	86·25	6 6025	72·5	74 2	...	...	906·66	290
$1\frac{4}{20}$	82·8	6 3384	69 6	72 8	...	...	822	277·71
$1\frac{3}{20}$	79·35	6·0743	66·7	71·3	...	...	747·3	272
$1\frac{2}{20}$	75·9	5·8102	63 8	69·7	...	...	680·88	252 69
$1\frac{1}{20}$	72·45	5.5461	60·9	68	...	...	621·47	210 8
1	69	5·282	58	66 4	...	...	568*	229 33
$\frac{19}{20}$	65·55	5·0179	55·1	64·75	...	...	519·61	218 23
$\frac{18}{20}$	62 1	4·7538	52·2	63·1	...	4632*	475·63	207 48
$\frac{17}{20}$	58·65	4·4897	49 3	61·27	...	2938·66	435·47	197·
$\frac{16}{20}$	55·2	4 2256	46·4	59·5	...	2092*	398·66	187·
$\frac{15}{20}$	51·75	3·9615	43·5	57·5	...	1584*	364 8	177·23
$\frac{14}{20}$	48·3	3·6974	40·6	55·6	...	1245·33	333·53	167 75
$\frac{13}{20}$	44·85	3·4333	37·7	53·6	...	1003·42	304·59	158 56
$\frac{12}{20}$	41·4	3·1692	34 8	51·5	...	822	277·71	119·64
$\frac{11}{20}$	37·95	2·9051	31·9	49·25	...	680·88	252·69	141
$\frac{10}{20}$	34·5	2·6410	29	47	...	568*	229·33	132·57
$\frac{9}{20}$	31·05	2·3769	26·1	44·5	4632*	475·63	207·48	124·39
$\frac{8}{20}$	27 6	2·1128	23·2	42	2092*	398·66	187	116·44
$\frac{7}{20}$	24·15	1·8487	20·3	39·3	1245·33	333·53	167·75	108·7
$\frac{6}{20}$	20·7	1·5846	17·4	36·4	822	277·71	149·64	101·18
$\frac{5}{20}$	17·25	1·3205	14·5	33	568*	229·33	132·57	93·86
$\frac{4}{20}$	13·8	1·0564	11·6	29·7	398·66	187	116·44	86·73
$\frac{3}{20}$	10 35	·7923	8·7	25·75	277·71	149·64	101·18	79·79
$\frac{2}{20}$	6·9	·5282	5·8	21	187	116·44	86·73	73·
$\frac{1}{20}$	3·45	·2641	2·9	14·75	116 44	86·73	73	66·43

* Air of 60° has its volume increased—

Double at . . . 568°	Fivefold at . . . 2092°	Eightfold at . . 3616°
Threefold at . . 1076°	Sixfold at . . . 2600°	Ninefold at . . . 4124°
Fourfold at . . . 1584°	Sevenfold at : . 3106°	Tenfold at . . . 4632°

SECTION IV.

ON THE APPLICATION OF THE SYSTEM OF WORKING WITH COMPRESSED AIR, TO STEAM BOILERS.

76. WHERE space is of no object in a steam engine, and a large grate, a large boiler, and a high stack are admissible, the use of compressed air is unnecessary. Whenever, on the contrary, *space* and *weight* have to be economised (and the importance of doing so in marine engines and locomotives can scarcely be exaggerated), aiding the draught in the stack by blowing the fire with compressed air ought to be considered indispensable, and must and will one day be so deemed, inasmuch as it is a vastly more economical method of producing the keen draught required, than that at present employed.

The fuel burnt per hour per square foot of fire-grate is—

In Cornish engines from	$3\frac{1}{2}$lbs.	to	4lbs.
In factory and marine engines from	10	,,	16
In locomotives	80	,,	100

The number of square feet of heating surface in boiler required to evaporate 1 cubic foot water per hour = I. H. P is—

In Cornish boilers	70		
In factory and marine boilers . .	9	,,	11
In locomotives	6		

The number of square feet of heating surface to each square foot of fire-grate is—

In Cornish boilers	40		
In factory and marine boilers . .	13	to	15
In locomotives	50	,,	70

77. In Cornish engines, with only a consumption of 4lbs. of coal per hour, per square foot of fire-grate, a very moderate draught only is required; consequently the temperature of the products of combustion, after they have yielded all their available heat to the boiler, sufficing for this purpose, there is no expendi-

ture of fuel for the sake of producing rarefaction in the stack, and hence one source of their economy. They do not, *in consequence* of their *slow draught*, produce more perfect combustion than other classes of engines, as is commonly but erroneously supposed (for there is no connection between the perfection of combustion and the rate at which it is effected); but the fuel wasted by other engines in producing a keen draught, they employ in the generation of steam.

78. Some persons entertain the chimerical notion that when the products of combustion leave the boiler, they ought to be reduced nearly to the temperature of 212°, or at least to a temperature but little above that of the water contained within. Till boilers however can be made infinitesimally thin, there must always remain a considerable difference between the temperature of their internal and external surfaces, (at least of such portions of the latter as are exposed to the heat of the flues,) increasing with the thickness of the boiler plate; for the temperature of a transmitting surface, must be *plus* that of a receiving one. This rule applies with full force to the temperature of the current of heated gases, and the surface of the boiler to which they impart heat, since here we get only *temporary* contact for a very *short period* of time. Air is besides a bad conductor of heat, and in addition, we have to take into consideration the fact, that as bodies *approximate* to each other in temperature, the rate of the transmission of heat becomes *rapidly* diminished; the law of 'cooling by contact,' for gases, being, that when the difference of temperature is doubled, the velocity of cooling is increased 2·35 (Petit and Dulong). For these reasons, I am totally incredulous as to many of the tales told of the extraordinary extent to which the products of combustion are cooled down, in certain instances, before leaving the boiler, and believe parties deceive themselves, by being unaware how high a temperature may be borne by the hand without inconvenience, when the draught is slow.

79. The path by which the utmost practicable economy can be attained, is obviously pointed out by the preceeding considera-

tions to be, by introducing the feed water immediately over the last portion of the flue traversed by the heated air before it enters the stack, and by diminishing the thickness of the shell of the boiler, which latter can only be done with safety, by making it consist of an aggregate of cylinders or tubes of moderate dimensions, instead of one enormous vessel, as at present. The change proposed, would be attended with the further advantage, of presenting more *surface* for the same *capacity*, thus enabling the size and weight of the boiler to be greatly diminished.

80. The first desideratum with regard to the place of admission for the feed water, is carefully studied in the Cornish boiler, but the second, is by no means fulfilled; and considering its enormous size, I believe it would be quite possible to construct a boiler on the principles above mentioned, where, as a question of first cost, the extra workmanship would be fully compensated for, by the diminished size and weight, whilst the thinner shell, would produce some addition to the economy in fuel.

81. If we allow 50° for the difference in temperature between the interior boiler surface in contact with the water, and the exterior in contact with the heated products of combustion, and 150°, when the draught is very slow, for the excess in temperature of these products, over the boiler surface at the instant of quitting it, making together a difference of 200° between the temperature of the water in the boiler, and that of the gases entering the flue, we shall I believe be making an estimate of a degree of perfection very rarely attained in practice.

82. If then a Cornish boiler works at 75lbs. pressure, the temperature of the water within will be 308°, and 308° + 50° + 150° = 508° for the estimated temperature of the gases at the moment of their quitting the boiler and entering the stack; and even in a low pressure engine I greatly doubt the practicability of ever reducing the temperature below 450°. In fact such temperatures, or any near approximation to them, can only be attained in cases where, as in the Cornish engine, the consumption of fuel per square foot of fire-grate is very small, the

draught slow, and the fuel not wasted to produce highly rarefied air in the stack.

83. In factory engines, where a draught is required sufficiently rapid to burn from 12 to 16lbs. of fuel per square foot of fire-grate, with the flues of the usual horizontal and winding form, I doubt the practicability of reducing the temperature of the products of combustion below 550° or 600°; and even to realize this, a high stack and capacious boiler will be necessary, and with these adjuncts, in this class of engines the employment of compressed air may be dispensed with.

84. In marine engines however, and still more in locomotives, where a fierce draught is required, a high stack inadmissible, and economy of space necessary, all the conditions exist which render the use of compressed air advantageous, and I believe its application to these two classes of engines to be imperatively necessary, if economy is to be attained.

85. In marine engines evaporating from 14 to 16lbs. of coal per square foot of fire-grate, where moreover, from the desirability of having a small boiler, the products of combustion have to be forced through small tubes, and this accomplished without the aid of the elevated stack of the factory, nothing but a very high degree of rarefaction in the chimney can furnish the requisite draught, and it is next to impossible under the circumstances present, that the products of combustion can leave the boiler at a lower temperature than 800°, a temperature entailing an enormous waste of fuel. To burn off the quantity of fuel required in the limited grate area, a keen draught is indispensable; and if the power to produce this, is to be attained by the ascentional force of the column of heated air in the stack, when the stack is of limited height, the temperature *must* be high, and the waste of fuel great: these vicious consequences are inevitably *linked together*, and there is no means of escape, but by generating the force required for the keen draught in a cheaper way, and calling in the aid of compressed air, which, by enabling the extent of heating surface in the boiler to be increased, and the

draught still maintained, would cool down the current of gases from the fire to the more economical temperature of 400° or 500°.

86. The whole question of draught in steam engines, is one of ratio of power, to space, and *cæteris paribus*, the greater the concentration required, the greater the draft necessary. The amount of rarefaction requisite to produce a given draft, is dependant upon: 1stly, *resistance*, comprehending area and form of grate bar openings, thickness and closeness of the layer of fuel, and area and direction of flues, whether horizontal or vertical, curved or straight; and 2ndly, upon *height of stack*. The greater the resistance, and the lower the stack, the higher the amount of rarefaction required to produce a given draft, and *vice versâ*.

87. It is through losing sight of the intimate mutual dependance of these conditions, and of the necessity which exists for each being adjusted to the other, that so many abortive attempts have been made to increase the evaporative power of boilers, and economize fuel, by suspending a vessel for feed water at the lower part of the stack. The effect of such an expedient being to diminish the draft, if it were attempted to burn the same quantity of fuel on the same area of grate bar, as had been previously done, unless the spaces between the bars were widened, or the height of the stack increased, the result would be, that an insufficient quantity of air would pass, for the combustion of the gaseous products of the coal, unless we suppose that the quantity passing before was too great; but as the opposite defect is more common, the probable result would be as before stated, so that the little heat saved at the bottom of the stack, being counterbalanced by the more inefficient combustion, the result produced, in an economical point of view, would be *nil*, or something nearly approaching it, which, as far as I can learn, is the usual product.

88. Such contrivances are in fact expedients for increasing the heating surface of boilers, which, it is evident, cannot be indefinitely extended with advantage, inasmuch as its proper ratio is

confined within certain limits, determined by the draught necessary to make a certain area of fire grate do the work demanded of it. In short, nothing can more clearly show how completely the subject has been shrouded in mist, and the general prevalence of the want of any comprehensive view of the principles involved in it, than the many absurd and futile attempts which have been made to produce effects as intrinsically unattainable, as perpetual motion, or the philosopher's stone; for whilst the high amount of *rarefaction* in the stack, is the *necessary condition*, by which the *force* of *draught* required for burning off 16lbs. of coal hourly per square foot of grate area is generated, it is nevertheless sought to remove the former, and retain the latter.

SECTION V.

ON THE ECONOMY TO BE ATTAINED, BY INCREASING THE TEMPERATURE OF FURNACES.

89. THE existence of this very important channel for effecting economic results, seems hitherto to have escaped due recognition. The principles on which its value depends, may be briefly explained as follows. It is only that portion of the heat of a furnace which is in *excess* over the temperature of the body to be heated, which constitutes in reality, *available heat,* conducive to the performance of its office. Thus the nearer the temperature of the body operated upon, approaches the temperature of the furnace, the larger is the portion of the heat of the latter which becomes ineffective, whilst the more the temperature of the furnace predominates, the larger becomes the proportion of serviceable heat, to the whole heat generated. Therefore, if by any means the intensity of the heat of a furnace

can be heightened, *its efficiency will be increased in the ratio of the accession made to its surplus heat,* (or the degree by which it exceeds the temperature of the body to which heat is to be imparted); so that for processes requiring very high temperatures, and where the ordinary heat of the furnace is but slightly in excess, a very small increment of temperature, will be productive of a great efficiency, and corresponding saving of fuel. As the principle involved is an important one, from the wide field it opens up for practical results, and has never yet been treated on, I shall do my best to make it intelligible to the reader.

90. Let us suppose, by way of illustration, that there is some process of manufacture carried on in a vessel containing 120 gallons of hot water, and that to carry it on favourably, the temperature of the water must never be allowed to fall below 200°, and further, that the loss by radiation and conduction from the sides of the vessel, is such, that in order to insure this temperature being maintained, it is necessary to keep a constant stream of boiling water at 212° flowing in at one end, at the rate of 2 gallons per second, and an equal quantity of partially cooled water, just on the verge of falling below 200°, constantly flowing out at the other. At this rate, the whole contents of the vessel, viz. 120 gallons, will be discharged and renewed every minute. The loss by cooling, will amount therefore, to 120 gallons of water cooled 12° per minute, and the fuel required to carry on the operation, will be, the quantity necessary to raise 120 gallons of water to the boiling point, every minute, or supposing the atmospheric temperature to be 56°, to impart 156° of heat to 120 gallons of water per minute, which, we will assume, requires in practice, 26 ounces of coal per minute.

91. Now let us suppose a means is found of imparting an additional 12° of heat to the supply water. Since the loss by radiation, is such that 120 gallons of water lose 12° of heat per minute, they will be 2 minutes* losing 24°, and consequently

* The slight increase in the velocity of cooling, with the increase in temperature, is too trifling to affect the argument.

this trifling addition of $\frac{1}{13}$ more heat, will enable half the amount of supply, or 1 gallon at 224°, instead of 2 gallons at 212°, to suffice for preserving the temperature from falling below 200°; and the contents of the vessel will only require to be renewed every 2 minutes, instead of every minute, whilst the saving of fuel per minute, will be the difference between the quantity of coal required to raise 120 gallons of water 156°, and that required to raise 60 gallons 168°, or nearly half; the quantities being 14 ounces in the latter case, and 26 ounces in the former. If we assume however, that the amount of additional heat imparted to the water, is obtained by some contrivance for making the combustion more perfect, which we should do, to *make the parallel and argument as regards furnaces complete, then the result will be, that this trifling addition of $\frac{1}{13}$ to the temperature, will effect a saving in fuel amounting to half.*

92. Precisely the same considerations which apply to a manufacturing process requiring to be carried on in a vessel of water of a certain temperature, apply to the operations carried on in furnaces, the only difference besides that of temperature being, that the fluid employed in one case is flame, or hot air, and in the other, hot water.

93. A large class of furnaces may be regarded as vessels in which changes are wrought in certain substances, by their being immersed in a bath of flame or hot air of a given temperature, either with, or without being subjected at the same time to certain manipulations, and the operation of certain chemical agents; and, as in the case of the water vessel, to preserve this temperature, it is requisite to have a constant supply of the fluid used, whether air or water, *plus* the temperature required to compensate for the loss by radiation and conduction, together with a means of egress, for that which has become *minus*.

94. Now the important principle involved in the matter under discussion, as I have before explained, is, that if, by any means, we are enabled to increase our temperature, *such increase will effect a saving of fuel in the direct ratio of the proportion it*

bears to the DIFFERENCE between *the temperature we were previously generating*, and *that which the process we are carrying on demands*. No matter how *small* the amount of that difference may be, if we succeed in gaining it, we at once diminish our consumption of fuel by $\frac{1}{2}$,—if we gain twice as much, by $\frac{3}{4}$, &c., &c. Let us suppose, in illustration, that we are generating an atmosphere of 3,200°, and that our process demands 3,000°, and that, in order to maintain it, we require to renew the contents of our furnace four times in a second, could we increase the temperature of our supply by 200°, thus making it 3,400°, twice in a second would suffice, and the addition of an amount of heat represented by $\frac{1}{16}$ of our consumption of fuel, would lessen this *consumption one half; or, under the same conditions, could we augment our temperature 600°, and thus raise it to 3,800°, once* in a second would suffice for renewing the contents of our furnace, and we should then have the addition of an amount of heat represented by $\frac{3}{16}$ of our previous consumption, diminishing this consumption four-fold.

95. In Staffordshire, 24 cwt. of coal (long weight 120lbs. to the cwt.) is consumed to produce from pig, 1 ton of puddled iron, the consumption being about 240lbs. per hour, or 4lbs. per minute. Now since oxygen is to carbon, in carbonic acid, as 8 to 3, and oxygen to hydrogen, in water, as 8 to 1, 4lbs. of coal will require for perfect combustion, $10\frac{12}{13}$lbs. = 120 cubic feet of oxygen, and since oxygen is to nitrogen (by volume), in atmospheric air, as 1 to 4 = 600 cubic feet of air; and the products resulting will be: 101·08 cubic feet of carbonic acid, 37·84 cubic feet of steam, and 480 cubic feet of uncombined nitrogen; total 618·92 cubic feet of gas. Estimate the temperature at 3,108°, and multiply the volume of gas by 7 for expansion, and we find that 4,332·44 cubic feet of rarefied gases, pass through the furnace per minute, ÷ 60 = 72·273 cubic feet per second. And finally, estimating the area of a puddling furnace between the bridges, at 36 cubic feet, we find to our surprise, that it is unquestionably filled and emptied twice in a second.

96. Now, if we estimate the temperature required for the process of puddling, at 3,000°, which must be a very near approximation to the truth (since the melting point of pig-iron is found by Daniel's pyrometer to be 2,786°), and suppose that the products of combustion pass over the fire bridge and enter the body of the furnace at a temperature of 3,300°, then it appears, that since to maintain the necessary temperature, the contents of the furnace have to be renewed twice in a second, the loss of temperature, by radiation, conduction, &c., is at the rate of 600° per second. If therefore by any method we could succeed in increasing the temperature generated by 300°, and thus raise the atmosphere produced by the furnace to 3,600°, since we have found that the rate at which the cooling process goes on, is 600° per second, we should only have to renew the contents of our furnace once* in a second, instead of twice, to maintain the requisite temperature of 3,000°, and should effect a saving of 50 per cent.

97. In mill or heating furnaces, used for the manufacture of iron, the result of heightening the temperature would be equally beneficial. When first charged with cold iron, the heating goes on rapidly, *but the rate at which it proceeds, constantly diminishes as the temperature of the iron approximates to that of the furnace*, and at last becomes very slow. It is during this latter period, that the beneficial effect of a more intensely heated furnace, becomes most conspicuous. Although I have denominated that portion of the heat of a furnace which constitutes its *difference* (in excess) over the temperature of the body to be heated, its *available* heat, it would be a grave error to suppose that the whole of this *excess* is transferred and usefully employed in the operation. Such would be the case were the products of

* The slightly increased rate of cooling, which would result from the increase of temperature is here disregarded, as too trifling to affect the argument. The law of cooling by contact for gases, is, that where the difference of temperature is doubled, the velocity of cooling is increased 2·35.—*Petit* and *Dulong*.

combustion and the body to be heated, kept a considerable time in contact; but in a *rapid transit*, as occurs with the heated gases of a furnace, only a certain ratio of this *excess*, in proportion to the measure of the excess itself, the extent of surface exposed, and the time occupied in the transit, can be left behind; and, considering the conditions of the furnaces of an iron work, I regard it as impossible that more than half the excess can be imparted, even at the most favourable period, that is to say, when the furnace is newly charged with cold iron, and the difference of temperature is greatest.

98. Now if we suppose the temperature of the iron to be 100° when placed in the furnace, the temperature generated by combustion to be 3,300°, and that half the *difference* (in excess) or surplus heat, when this surplus is 3,200°, enters the iron, we shall have at the commencement (3,300°—100°=3,200°÷2= 1,600°) within a fraction of *half* the whole heat generated, imparted to the iron. When however the iron has attained the temperature of 1,700°, and the surplus heat becomes halved, we shall have only 680° communicated to the iron, or a little more than a *fifth* of the whole. When the iron has reached the temperature of 2,500°, and the surplus heat becomes quartered, only 290 parts of heat out of 3,300 generated, or less than $\frac{1}{11}$, will be profitably applied. Whilst if we suppose that iron requires to be raised to 3,200° to bring it to a welding heat, the state of things when it has attained the temperature of 3,100°, and is beginning to receive its last 100° of heat, will be as follows:—Out of 3,300 parts of heat generated, only 52, or less than $\frac{1}{64}$, will enter the iron, the remaining 3,248 parts, or more than $\frac{63}{64}$ of the whole, being wasted. Could we however succeed in increasing the temperature of our furnace by 400°, thus raising it to 3,700°, the state of things at the same point would be, that 206 parts of heat, or $\frac{1}{18}$ instead of only $\frac{1}{64}$ of the whole heat generated, would enter the iron; thus exhibiting the fact of an addition of temperature to the amount of $\frac{1}{8}$, increasing

the velocity of heating, and consequently the efficiency of the furnace at this crisis, fourfold.

99. These laws have such an important practical bearing, and their existence is at the same time so little suspected, that with a view to their more complete display and elucidation, I have exhibited them in a tabular form; and if I do not greatly err, they deserve to command as much attention, as they will unquestionably excite surprise. The tables contrast the effects of two furnaces (one heated to 3,300°, the other to 3,700°,) in imparting heat to iron at five different stages, whilst being raised to a welding heat; clearly shewing, that although the rate at which heat is communicated, rapidly diminishes, as the temperature of the iron increases, *yet a very trifling addition to the temperature of the furnace*, is capable of producing a great result in retarding the *rate* at which the diminution of heating proceeds, and consequently, in the economic working of the furnace. Column A gives the temperature of the furnace, B the temperature of the iron, C the difference in favour of the furnace, D the portion of this difference imparted, E the proportion of the whole heat generated imparted, F the velocity at which the heating proceeds, calling the smallest velocity 1.

A.	B.	C.	D.	E.	F.
3300°—	100°=	3200°......	1600......	·484......	30·49
3300°—	1700°=	1600°......	680......	·206......	12·97
3300°—	2500°=	800°......	290......	·087......	5·52
3300°—	2900°=	400°......	123......	·037......	2·35
3300°—	3100°=	200°......	52......	·015......	1
3700°—	100°=	3600°......	1871......	·505......	35·64
3700°—	1700°=	2000°......	911......	·246......	17·35
3700°—	2500°=	1200°......	485......	·131......	9·25
3700°—	2900°=	800°......	290......	·078......	5·52
3700°—	3100°=	600°......	206......	·055......	3·93

To facilitate comparison, the results are arranged below in parallel columns, the prefix + denoting those of the hotter furnace.

B.	C.	+C.	D.	+D.	E.	+E.	F.	+F.
100°	3200°	3600°	1600	1871	·484	·505	30·49	35·64
1700°	1600°	2000°	680	911	·206	·246	12·97	17·35
2500°	800°	1200°	290	485	.087	·131	5·52	9·25
2900°	400°	800°	123	290	·037	·078	2·35	5·52
3100°	200°	600°	52	206	·015	·055	1	3·93

100. In treating this question, I have endeavoured to place conspicuously before the reader the great advantages attendant upon a *slight addition* of temperature, irrespectively of the question as to whether, in our present position, we are, or are not able to profit by this law; believing, that even if a negative be the correct answer, it is nevertheless not the less desirable that we should possess a knowledge of the *direction* in which our attention may be turned, with the greatest probability of obtaining important results.

101. The most efficient method that I am acquainted with, for increasing the temperature of reverberatory furnaces used for the manufacture of iron, is the use of compressed air, in a closed ash-pit, thus creating *artificially*, the state of things present, when a steady breeze sets into the ash-pit. It is a fact, that a furnace thus favourably situated, will heat *three* charges of iron, whilst its opposite neighbour in other respects its equal, is heating only *two*; and the wonder is, that the hint thus conveyed, has not been sooner acted upon, and that state of efficiency which now only has place with a few furnaces, and at uncertain intervals following the caprice of the wind, made the permanent condition of all.

102. In proportion as the temperature of furnaces becomes increased, does it become important to obtain a fire-brick material of the best possible description, particularly for the sides of the grates. The presence of alkalies, or iron, is fatal to the quality of a clay for this purpose. When free from these ingredients, its

power of resisting heat is almost in a direct ratio to the proportion of silex it contains, and I have long been of opinion, that the quality of what is termed our best fire-brick, might be greatly improved by incorporating with the clay, an additional quantity of pure silecious sand (which may be procured, where not found native, by grinding pure sandstone), the requisite cohesion of the materials being produced, by subjecting the brick in its manufacture to a high pressure. This method I am informed, has been recently adopted with the celebrated Dinas clay, at Neath, with the result of producing a fire-brick, containing 95 per cent. of silecious matter, and far surpassing in quality anything before known, since for very intense heats, it is found to exceed Stourbridge in durability four-fold.

103. Whatever method of working furnaces be employed, constructing the envelope so as to prevent as much as possible the passage of heat, must ever be an unmixed good as far as economy of fuel is concerned, and the better the fire-brick material employed, the more completely can the principle be carried out, without neutralizing the economy attained in fuel, by the extra expense in repairs, resulting from the increased rapidity with which the bricks are burnt out. By constructing furnaces with hollow walls, and filling the intervening space with cinder dust, or some other incombustible bad conductor of heat, a great saving of fuel might be effected; but to what extent this would be counterbalanced in an economical point of view, by the increased amount of materials and labour necessary to keep them in repair, with the quality of fire-brick generally in use at present, I am not prepared to say.

SECTION VI.

ON FEEDING FURNACES WITH HOT AIR.

104. To discover the amount of saving in the consumption of fuel, capable of being attained by the entire substitution of hot air for cold, where such air is heated from the waste products of the furnace itself (and which, as far as I am aware, has not before been attempted), I instituted the following calculation:—

According to the recent researches of Andrews, 1 part of carbon will raise 14,220 parts of water 1°, and 1 part of hydrogen will raise 60,854 parts of water 1°.

Now if the specific heat of carbonic acid be called ·22, that of nitrogen ·27, and that of steam ·847, then carbon, inflamed with its exact equivalent of oxygen to form carbonic acid, will produce an atmosphere of 17,628°, and with its exact equivalent of atmospheric air, an atmosphere of 4,058°; hydrogen, with its exact equivalent of oxygen to form vapour, an atmosphere of 7,982°, and with its exact equivalent of atmospheric air, an atmosphere of 3,871°.

105. Assuming 100 parts of coal to consist of 80 parts of carbon, and 5 of hydrogen, which is in the proportion of 16 parts of the former, to 1 of the latter, and leaving out of view the 15 parts of miscellaneous matter as unessential, then, since carbon, inflamed with its equivalent of air, produces a temperature of 4,058°, and hydrogen of 3,871°, coal, if compounded of carbon and hydrogen, in the proportion of 16 parts of the former to one of the latter, would produce an atmosphere of 4,047°.

106. Considering however the impossibility of admitting just the precise quantity of air to produce this state of theoretical perfection, the fact that coal contains a small quantity of nitrogen, and also that some heat passes into the sides of the grate, we may pretty safely assume that the heat generated in the body of the furnace, seldom exceeds 3,300°, and is probably

more frequently below, than above this point. Nevertheless, as this number, which is certainly about what theoretical deductions would lead us to fix upon, coincides with the observation of Professor Daniel with his pyrometer, who found 3,300° to be the greatest heat of an air furnace, I shall adopt it as the basis of my calculation.

107. Now, as lead, the melting point of which is 600°, melts with extreme rapidity in the hot air flues of a furnace, running like sealingwax in the flame of a taper, we certainly shall not err on the side of excess, in estimating the temperature of the air at 720°, and if we substract 60° for the atmospheric temperature, we get an addition of heat of 660°, or $\frac{1}{5}$ of 3,300°, the whole temperature generated, shewing a saving in fuel of 20 per cent.; and if, as is probably the case, a portion of the diminution in the heat between the theoretical number 4,047°, and that which experiment shows 3,300°, is to be attributed to a surplus quantity of air passing through the fire, and lowering the temperature of the furnace, then this per centage of saving by the use of hot air, should be increased.

108. Having attained to a clear perception of the immense saving of time and fuel, which would accrue in all operations where it is required to impart a temperature nearly equal to that generated (and where consequently the surplus heat is very small), by even a trifling addition to the temperature of the furnace, the first method that suggested itself to me for attaining this object, was by supplying the fire with hot air under pressure. Having entered into a calculation for the purpose, and found that an additional quantity of heat equal to 20 per cent. of the whole generated, was to be obtained in this manner, I felt sanguine as to the results to be elicited. Whilst however, *time* and *intensity* being disregarded, and looking solely to the *total quantity* of heat obtainable, I have found the full amount of saving promised by theory, confirmed in practice, my anticipations of an *increase* in *the temperature and heat-imparting powers* of reverberatory furnaces, by feeding them with hot air, were not

realised. Surprised at this result, which then appeared to me as extraordinary as it was unexpected, and not even a recognition of the fact, much less its solution, being to be found in the literature of the subject, I consulted living authorities for information, but with no better success. Indeed, I found their minds as much in doubt as to the correct explanation of the apparent anomaly, as my own. Curious, as to the cause of the phenomenon I witnessed, in occuping myself with its consideration, I have been led to form some conclusions on the subject, which I will lay before the reader.

109. I must premise, that the temperature of flame* is greatly above that required for the ignition, and white heat of solid bodies, as is shown by the fact, that during the slow combustion of gaseous bodies, when the heat developed is not sufficient to render the gaseous matter itself luminous, it is nevertheless adequate to produce ignition in solid bodies exposed to it.

110. *Flame*, indicates the intense *concentration* of heat which has place, is present, or comes into being, at the *moment of its* (i. e. flame's) *generation* by chemical combination, *before*, this heat has become diluted by the resulting expansion. The power of the gaseous products of combustion to communicate heat after their expansion, and when flame has disappeared, is weak and feeble, compared with the direct action of the latter. The more completely the body of a reverberatory furnace is filled with the flame of bicarburetted hydrogen, the more efficient is its working condition. A stream of bicarburetted hydrogen gas, mingled with its exact combining equivalent of atmospheric air (or fifteen times its own bulk), propelled cold from the grate, and only ignited as it passed over the bridge, and was in the act of entering the body, or working chamber of the furnace, would be the acme of perfection, where the power of rapidly imparting intense heat is required. The combustion which takes place in the grate, is in reality not only useless, but injurious, except as far as generating gas is concerned; inasmuch

* A filament of platina may be fused in the flame of a common candle.

as the larger the proportion of the *rarefied products* of the combustion accomplished in the grate, passing through the working chamber, the smaller will be the amount of the *flame-yielding gas*, the power of which to impart heat, we have seen to be so vastly superior.

111. One cause of the impaired heat of reverberatory furnaces supplied with hot air, must then be sought in the fact, that gaseous combustion being accelerated by it, a larger amount of chemical union takes place in the *grate*, and less in the *body* of the furnace, where it would be more beneficial. This result may to a certain extent be counteracted, by shortening the bridge and fire-grate, in the line of the longitudinal axis of the furnace, and perhaps, in certain cases, it might also be advisable, to make a similar alteration in the body of the furnace itself.

112. The next point to which I shall call attention, as one of the causes of the diminished heat of reverberatory furnaces supplied with hot air, is, the greater state of expansion and tenuity, attained by the mixture of air and coal gas, *prior* to inflammation, and the consequent result, that in a given *space* there is a less *quantity* of heat developed by their union. There is, no doubt, more heat contained in the products of combustion from a given *weight* of coal gas and air, heated before ignition to 720°, than would be contained in the products of the combustion of the same quantities by weight, of gases ignited at the temperature of 60°. When we take given *measures* however instead of given *weights*, the case is reversed. Gases at 60°, expand $\frac{1}{508}$ of their bulk for each degree of heat imparted, so that their bulk at 720°, compared with their bulk at 60°, is as 2·3 to 1. Consequently a given *space* filled with coal gas and air at 60°, will contain 2·3 times the *weight*, of the same *measure* of these mixed gases at 750°, and would develop 2·3 times the quantity of heat by combustion. Making an allowance however of 20 per cent. for the heat already present in the gases at 720°, the result will be, that supposing 1000 parts of heat to be contained in the products of the combustion of a given *bulk* of coal gas and air at 60°, only 521 parts, or little more than half the quantity, will be contained in the products of the combustion of an equal *measure* of these

mixed gases at 720°. Hence the flame resulting, is characterised by comparative tenuity.

113. Now there can be no doubt as to the fact, that the average temperature of the mixture of air and coal gas which escapes combustion in the grate, to be ignited in the body of the furnace, is higher when the furnace is fed with hot air, than with cold, and we have already seen, that variations in the state of rarefaction of gases prior to ignition, produce a potent practical effect, with regard to the capacity of a given volume, for imparting heat. On the supposition that the area of the working chamber of a reverberatory furnace, is equally divided between the products of combustion of the gases which have combined in the grate, and those still remaining to be inflamed; that the temperature of the latter when the furnace is fed with cold air is 568°, and when with hot air 898°, this would give a deficiency of 17 per cent. in the amount of heat furnished by the combustion which takes place in a given time in the body of the furnace, an estimate which I think can scarcely be beyond the truth.

114. The third, and last circumstance that I have to adduce in explanation of the effect of hot air in diminishing the heat of the working chamber of reverberatory furnaces, is, that from the greater tenuity of the air, it does not produce the same *frottement* and attrition, in its passage through the fuel, nor (owing to its less sudden expansion) the same amount of *quasi* detonation or percussion, at the instant of combustion. The disintegration of the carbon, being thus retarded, at the same time that the escape of the hydrogen, is facilitated by the heat, the result is, that the ordinary relation between the rate of consumption of these two constituents of the coal is deranged, and the gases passing from the fuel, contain an undue proportion of hydrogen, whilst the carbon accumulates as cinders on the bars. If the specific gravity of air at 60° be termed 1, then the specific gravity of air at 720° will only be ·434, or considerably less than half, so that, moving at the same velocity, the force of impact becomes diminished more than two-fold. If we now picture to ourselves the effect of a pair of kitchen bellows, and how rapidly the

cinders are disintegrated before the *stroke* of the blast, and then imagine the diminished effects that would ensue, were the force with which the air strikes the carbon diminished to less than half, we shall readily understand *why* the combustion of the carbonaceous portion of the fuel, proceeds more slowly when the furnace is fed with hot air, than with cold.

115. On this theory we should be led to expect a considerable difference in the adaptability of different varieties of coal for use with hot air, an inference fully carried out by practice. There is a great variation as to the increased ratio with which the cinders accumulate on the bars, according as the texture and composition of the coal, render the disengagement of the carbon more or less facile, and there can be little doubt but that, *cæteris paribus*, the more the carbon of a fuel is disposed to assume the gaseous form, as with cannel coal—or the less the quantity of hydrogen present, as with anthracite—the greater will be the chance of being able to seize the economic advantages attendant upon the increased quantity of heat attainable by the use of hot air, without having this heat so diluted, as to make the temperature inefficient.

116. It doubtless will excite the surprise of many to see an increase in the proportion of the hydrogen to the carbon, given as a reason for the falling off, in the temperature of a furnace, as it is a very common error to suppose hydrogen to be a much more efficient agent in generating heat than carbon. Such is undoubtedly the case weight for weight, but requiring 36 times its own weight of air for its combustion, whilst carbon only requires 12 times, and its product steam, having a much greater specific heat than carbonic acid, it does not produce by combustion with atmospheric air so high a temperature. For perfect combustion,

vol.	volumes		vol. steam	vol. CO_2*	vol. nitrn.	temper. generated
1 of hydrogen	requires	2½ of air, product	1	0	2	4,303°
1 of carbd. hydrogen	„	10 of air „	2	1	8	4,337°
1 of bi-carbd. hydrogen	„	15 of air „	2	2	12	4,341°

*CO^2 is the chemical symbol for carbonic acid, and denotes it to be composed of one atom of carbon, and two atoms of oxygen.

117. It is however in its deficiency in heating power with reference to its *volume** that we must seek for the cause of the diminution of temperature which occurs in practice, by substituting hydrogen for carburetted hydrogen. The difference between the quantity of air required by equal volumes of the two gases is so great, amounting as we have seen to four-fold, that with furnace arrangements adopted for carburetted hydrogen, that is, calculated to allow 10 volumes of air to pass with each volume of gas, it is next to impossible but that just in proportion as hydrogen is substituted for it, does the quantity of air passing, become an injurious excess.

118. It thus appears that three circumstances,—1st, an increased proportion of the combustion being completed in the grate,—2ndly, the higher temperature and consequent rarefaction attained by the gases prior to ignition,—and 3rdly, the retarded disintegration of the carbon on the grate bars, (and the resulting diminished quantity of combustible matter passing in a given time, and undue preponderance of hydrogen) all combine to neutralize—where a very high temperature is demanded—the economy, which might otherwise be attained by feeding the fire of reverberatory furnaces with hot air,—by attaching to the practice, the condition,—that just in proportion as it is carried out, does the flame in the working chamber become attenuated, and its power of rapidly imparting intense heat impaired.

119 To what extent impregnating the hot air with which the furnace is fed, with steam, by carrying water into the ash-pit, would prove a remedy for some of these evils, is an interesting subject for inquiry. The steam coming in contact with the ignited carbon would be decomposed, its oxygen would combine with the carbon, whilst the hydrogen would be disengaged, and pass off with the other gases from the fuel, to be ignited in the furnace chamber. It is a vulgar error to suppose that the whole amount of heat obtainable from fuel, is increased by the employment of water, for precisely the same amount of heat which is

* If the heating power of 1 volume of bi-carburetted hydrogen = 100, that of hydrogen is only 21·4, and that of carburetted hydrogen 71·4.

given out by the hydrogen when it enters into combustion and forms water, must have been previously abstracted from the ignited fuel in the grate, to effect the decomposition of the water. What takes place is not, correctly, speaking a *gain* of heat, but a *transfer*. The plan is an expedient for increasing the flame in the body of the furnace, at the expense of the glow fire on the fire-grate bars, thus transferring heat from the grate, where it is not wanted, to the working chamber, where it is most required.

SECTION VII.

ON THE ECONOMIC APPLICATION OF HEAT.

120. HOWEVER complete may be our arrangments for attaining perfect combustion, and eliciting from the fuel the whole of the heat it is capable of furnishing; unless we at the same time employ judicious measures for applying the heat thus obtained, to the best advantage, our previous successful efforts for the attainment of economy in its generation, may be rendered nugatory.

121. At an early period of my inquiries into the question of economy of fuel, I felt curious to know, what proportion of the whole heat generated in a reverberatory furnace for the manufacture of iron, actually entered the *iron*, and what proportion was dissipated and lost. Finding no information extant on the subject, and thinking it, an interesting point to determine the theoretical heating power of fuel in relation to iron, and contrast it with that actually obtained, I made the calculation which I here subjoin. So much doubt however hangs over the question of the exact specific heat of iron at high temperatures, that the results attained are not entitled to be considered as absolutely exact, but merely as offering a tolerably near approximation to the truth.

122. The consumption of coal in a puddling furnace in Staffordshire, is weight for weight, that of the pig iron worked.

Cast iron melts at 2,786° by Daniel's pyrometer. Say the iron is raised in the furnace to 3,060°, and allow 1,000° for its latent heat, this makes 4,000° imparted. The specific heat of iron at 212° is ·11; like other substances, its specific heat increases with its temperature, and is at 662°, which is the highest point that has been ascertained by direct experiment, ·125. From a consideration however of the amount of heat communicated by melted cast iron, to known quantities of ice or water, determined by M.M. Clement and Desormes, in connexion with its melting point, as fixed by Daniel, I consider myself warranted in assuming, that if I double its specific heat at 212°, viz. ·11, and call it, at the high temperature it attains in the furnace, ·22, a number higher than has yet been assigned to it, I cannot be below the mark.

123. If then we assume that 4,000° of heat is imparted to the iron in the furnace, that the specific heat of iron is ·22, that of water being 1, since, 1 lb. of coals is capable of raising 1 lb. of water 14,220°, $\therefore \frac{14220}{4000 \times 22} = 16{,}{\cdot}159$, the number of pounds of iron, 1lb. of coals is capable of raising 4,000°. Showing that in the present puddling furnace, the quantity of coals burnt, is sufficient to generate more than sixteen times the quantity of heat contained in the iron at any period of the operation.

124. In reverberatory furnaces used for melting cast iron, the quantity of coals employed is 15 cwt. to the ton of iron, or ¾ the weight of iron; showing, according to the previous calculation, that in the simple process of melting, a quantity of coals is burnt, more than twelve times sufficient to generate the heat actually imparted; a state of things certainly not discouraging the belief, that increased economy is attainable. In expressing this opinion however, I do not wish to be understood to advocate the chimerical notion, that the whole, or nearly the whole of the heat generated, can ever be made to enter the iron. I have, on the contrary, already stated,—as a law hitherto comparatively disregarded—that it is only the *difference*, by which the tempera-

ture of the atmosphere of the furnace, exceeds that of the objects subjected to it, which can be counted as *available* heat, for increasing the temperature of the latter, and consequently, that as the heat of the iron increases in intensity, an increased proportion of the heat generated by the fuel must pass out of the furnace unabsorbed.

125. The same considerations do not however apply to steam boilers. Here the temperature of the heat-receiving body, never exceeds a comparatively low point, and the heat of the furnace consequently always preserves so great a preponderance, that only a small fractional part of the heat generated, say from 10 to 15 per cent., need be allowed to pass away by the flue unabsorbed.

126. A peculiarity attached to steam boilers however, which has interfered with their reaping the full benefit of their favourable position in this respect, is, the necessity that exists for confining the flues to the lower portion of the boiler, and withdrawing them from contact with its surface, as soon as they reach to within about the height of a foot below the water level. If carried higher, the sides of the boiler above the water level are apt to become unduly heated. Whilst in this condition, the tenacity of the iron is dangerously lessened,* and if such a state of things be of frequent occurrence, the texture of the metal becomes permanently impaired, and changed from fibrous to crystalline. When this alteration in its physical structure has once taken place, there is an end to all safety; its strength can never be *relied* upon, and it is quite unfit to cope with any extra demand upon its powers of resistance.

127. When an engine is at work, the surface of the water is kept in a constant state of agitation, and fluctuates at each stroke of the piston, with the fluctuations in pressure consequent upon the periodic emissions of steam. When the engine is

* At the temperature of 720°, the strength of the boiler plate becomes impaired nearly 20 per cent. and the accidental over heating of a boiler, has been known to diminish its strength more than 30 per cent.

stopped, on the contrary, the pressure being steady and uniform, the surface of the water becomes comparatively quiescent. At such periods, should the flues be too near the surface, and the heat creep up the sides so as unduly to raise the temperature of the sides of the boiler immediately above the water, (now no longer incessantly wetting and cooling them with its pulsations,) it too often happens that upon the engine being set at work again, and the pulsations recommencing, the water, washing against the dry heated iron, is instantaneously flashed into steam, and a fearful explosion, scattering ruin and death around, is the result.*

1[illegible]. To obviate the danger of such lamentable catastrophes on the one hand—and on the other to release the upper half of the boiler from the embargo on its usefulness which forbids its being employed as a *generating* surface, and restricts the sphere of its operations to serving as a mere *reservoir* for the steam—I would propose to line it with some fibrous and porous material capable of sucking up water by capillary attraction, such, for instance, as course hempen cloth. This fibrous coating being kept in close apposition with the interior surface of the upper part of the boiler by means of a wire net work, and its lower edge descending on all sides to, or below the surface of the water, capillary attraction causes the water to ascend, as fast as it becomes evaporated, in the same way as oil or spirit ascends in the wick of a lamp. The sides of the boiler above the water level are thus constantly kept moist, and the possibility of their attaining a dangerous temperature prevented, at the same time that the wetted fabric in the interior, presents an additional surface for the generation of steam, thus uniting safety with economy.

* In confirmation of this view of the most frequent cause of explosions, it is a fact, that the great majority, occur immediately after an engine which has been stopped, recommences working and has made one or two strokes, and not during the time it is stopped, when the pressure, according to the prevalent theories which attribute explosions to *non*-acting safety valves, might be expected to be greatest.

SECTION VIII.

ON THE EMPLOYMENT OF WASTE HEAT.

129. SINCE I have shewn that the amount of *necessary* or rather *unavoidable* waste heat passing out of the furnace, increases with the temperature we require to impart, it follows, that in proportion as the processes we carry on in our furnaces require an intense heat, does the necessity for attending to this feature of economy increase, and that in none is it of higher importance, or capable of being made a greater element of saving, than in furnaces for the manufacture of iron.

130. To impress this distinction more closely upon the reader, I will contrast the circumstances of an iron furnace, with those of a steam boiler. In the former, the flame makes one short and rapid dart or transit, in a straight line and in one body from firebridge to fluebridge. To facilitate the comparison, I shall estimate the long and winding, or else subdivided flues of the latter, as equivalent to four short and rapid transits; and the temperature of the successive portions of the surface of the boiler traversed by the heated gases, at 500°, 400°, 300°, and 300°, respectively.

131. Assuming then, the temperature generated by a steam boiler furnace to be 3,000°, and that during the first transit, when the excess of temperature is 2,500°, half the surplus heat is imparted, the following table shews the quantity of heat transferred at each transit, and the amount remaining in the products of combustion at the moment of their quitting contact with the boiler. Column A is supposed to shew the temperature of the atmosphere of the furnace, B that of the boiler surface in contact with A, C the surplus by which A exceeds B, and D the quantity of heat transferred during each transit.

	A	B	C	D
1st transit	3000°	500°	2500°	1250°
2nd transit	1750°	400°	1350°	589°
3rd transit	1161°	300°	861°	331°
4th transit	830°	300°	530°	187°

leaving 643° for the temperature of the products of combustion at the moment of their leaving the boiler.

132. The preceding calculation is given as an illustration, and does not claim to be strictly accurate, still considering the figures are the actual result of the first hypothesis I made; the coincidence of their results with regard to the temperature at which the gases enter the chimney, with what we know to be the fact, is certainly remarkable, and affords ground for believing, that except in the *suddenness of the transitions*, they present a far from inaccurate approximation to what really takes place. A comparison between this table of the conditions which exist in a steam boiler, where the waste heat passing away seldom exceeds more than $\frac{1}{5}$ of that produced, with those of an iron furnace (see paragraph 99), where the waste heat, beginning at $\frac{17}{33}$, gradually rises to $\frac{63}{64}$ of the whole heat generated, will make sufficiently clear, the much greater necessity that exists for employing some means for utilizing the waste heat in the case of the latter, than in that of the former.

133. Here, it *is* most particularly, that the advantages of working with compressed air become apparent; for it is evident, that as long as this system is neglected, and the draught made to depend entirely upon the state of rarefaction in the stack, if we abstract more than a limited amount of heat from the gases passing through this channel, we shall lessen the amount of rarefaction, beyond what is compatible with the keenness of draught required.

134. The system—still adopted in many iron works—of discharging the products of combustion from the stacks of the puddling and mill furnaces unused, and getting up the steam in the steam boilers by means of separate fires expressly for the

purpose, exhibits an inexcuseable disregard of economy. Even supposing—as is doubtless the case—that under the present system of working exclusively by draught in the stack, the aggregate number of furnaces are adequate to supply sufficient heat to generate steam for the exigencies of the work itself; yet there are so many manufacturing and other industrial operations for which steam is requisite, that might be carried on without any inconvenience in immediate juxtaposition with an iron work, and carried on advantageously, inasmuch as no outlay for fuel for the generation of steam need be incurred, that there is no reason beyond supineness, why the present wasteful system should be perpetuated. On the contrary, economy dictates that all the surplus heat should be carefully preserved and conducted to one extremity of the premises, there, to be in readiness to let out for hire, for the purposes of any other manufacturing establishment which might be carried on adjoining—such, for instance, as mechanical engineering, saw mills, flour mills, cotton, woollen, and flax factories, candle making, soap boiling, baths and wash-houses for the workmen, &c. In short, so various are the processes, and multifarious the elegible channels for the employment of surplus heat, that the present system of waste, is quite indefensible.

135. The quantity of coal consumed in a puddling furnace is 240lbs. per hour, which, reckoning $7\frac{1}{2}$lbs. of coal per horse power, is sufficient to generate steam for 32-horse power. We have seen that the quantity of heat actually imparted to the iron, is but a small fractional part, $\frac{1}{16}$, of the whole heat generated, and it will therefore be a fair supposition to say, that by the use of compressed air, one half of the whole heat generated might be practically applied to the raising of steam. This would equal 16-horse power, or more than three-fold the quantity now available under the system of relying exclusively for the draught upon rarefaction in the stack. Taking however the extra heat capable of being released by the use of compressed air, at 10-horse power,

we shall have in an iron work containing 100 furnaces, a constant unnecessary waste of heat equal to 1,000-horse power, representing a waste of coals per year of 300 working days, of 24,107 tons, equal in money at 5s. per ton to £6,026, an amount of waste, which cannot but excite the regret of all who desire to see our national resources and productive powers turned to their best account.

136. In short, heat may, and *should* be regarded, as *equivalent to power, labour, time, money*;—all are mutually convertible, and if considered in the right point of view, it is just as absurd to waste one, as the other.

SECTION IX.

ON THE MANUFACTURE OF IRON.

137. The manufacture of iron has been brought to its present grade of perfection by practice, rather than by theory. Till the development of the science of chemistry characteristic of the present age, (which has made a contrary course a possibility), such has always been the case with the arts at their commencement.

138. A time however is probably not far distant, when science will vindicate her claims to utility, in this, as in other departments of human knowledge, and exert as beneficial an influence over the manufacture of iron, as she has already exercised over various kindred arts.

139. One great cause hitherto of the failure of scientific theories when applied to iron making, I am inclined to ascribe to our ignorance of the chemistry of high temperatures, a branch of the science most imperfectly understood, and the prosecution of which by experiment, is necessarily beset with great difficulties.

140. Affinities vary with temperature, and we do not at present know, all these variations. We are accustomed to regard

sulphuric acid as the most powerful of the acids, and phosphoric acid as among the weakest, and such is the case at ordinary temperatures; but if gypsum (sulphate lime), is heated to redness with phosporic acid, the sulphuric acid will be driven off, so extraordinary is the change in affinity wrought by the access of heat. At a slightly elevated temperature, potassium will take the oxygen from the carbon of carbonic acid, but at a white heat, the reverse takes place, and potassium is prepared by subjecting carbonate of potash with charcoal to the heat of a furnace. At a temperature above the freezing point, salt has no affinity for water, and crystallises in anhydrous cubes; whilst below the freezing point, it crystallises in prisms, which consist of a chemical union of salt and water, the bonds of affinity between which, the warmth of the hand is sufficient to destroy. If necessary, numerous other examples might be adduced, all conclusively showing that the chemical affinities of bodies are dominated by temperature.

141. Another circumstance not without its influence in throwing difficulty in the way of the application of science to the manufacture of iron, has been the large masses of solid materials operated upon,—so different from the manageable quantities of the laboratory,—and the consequent difficulty of realising that condition of chemistry, which exacts a thorough commingling of the particles of matter operated upon, requiring—as a preliminary for its attainment—the attraction of cohesion in solid bodies to be removed by solution or fusion. Hence the importance of obtaining in the hearth of the blast furnace, a state of fluidity sufficiently perfect, to allow of the complete segregation of the various matters according to their respective polarities, without which, various crudities and undeoxidised impurities, are carried down with the metal.

142. Chemical union however takes place only at imperceptible distances, atom must unite with atom, and something more than perfect fluidity is required to produce in many cases a minute commingling, of bodies varying greatly in specific

gravity or consistency. We might for example, stir quicksilver and water together for an hour, without having placed more than a very limited number of their particles in contact. This comparison is but an exaggerated illustration of what takes place in a puddling furnace, when it is attempted to improve the quality of the iron by an artificial flux. So imperfectly are the particles of iron subjected to its operation, that either no appreciable effect is produced, or only a partial effect, causing a want of homogeneousness in the texture of the iron, thus manufactured.

143. It is certain, that the quality of the iron made, is greatly influenced by the nature and quality of the alkalies, alkaline earths, and other fluxes present, provided we can present them in such a state of minute subdivision and dissemination amongst the other materials, as will ensure their chemical agency being exerted with the best effect. A great part of the beneficial influence of charcoal, in the manufacture of iron, arises in my opinion, from its containing in this state of minute subdivision, small quantities of potash, lime, magnesia, phosphoric acid, and manganese, which it *constantly* and *gradually* presents to the process going forward, in a quantity *precisely proportionate* to the rate at which the combustion, and consequently the process contingent upon the combustion proceeds, and I anticipate that great advantages may be obtained, by judiciously attempting to imitate those conditions, the value and utility of which, in the case of charcoal, are amply sanctioned by experience. The manner in which I would propose to do so, would be, by immersing coke in alkaline or other appropriate solutions, which might be forced into its pores by hydraulic pressure if desirable, thus producing an imitation of charcoal, which after being thoroughly dried, might be advantageously substituted for common coke, in the manufacture of iron.

144. The composition and strength of the flux solution, should of course vary with the nature of the ore, and the composition of the ashes of the fuel. Even where charcoal is employed, it might be advisable in certain cases to increase the natural quantity of alkali it contains, by treating it in the same way.

145. That an improvement would be effected in the quality of the iron produced—by the adoption of this system, particularly in the case of silecious and clay ores, does not admit of doubt; for the ashes of coal are not only wanting in those active fluxes possessed by charcoal, but contain a considerable portion of silex: and if, as appears to me most probable, the alloy of silicon—the most general and influential cause of bad pig iron—is *principally*, if not *exclusively*, furnished by the silex of the *fuel*, the most feasible preventitive would appear to be, to force a powerful *base*, into the pores of this material, and thus place it in *immediate contact* with the silicic acid, with which its union is desired. If this be not done, the silica *intimately blended* with the carbon, throughout the structure, of the coke and necessarily exposed from this association to the most intense heat, can scarcely fail of becoming deoxidised.

146. The requirements for making iron, are, 1st, the requisite chemical ingredients* in the requisite proportions; 2ndly, sufficient heat,=fluidity, to allow of the free motion of all the particles of matter; 3rdly, sufficient motion amongst the particles to ensure their adequate intermixture.

147. This view of the innocuousness of a high temperature, does not agree with the generally received opinion, that the inferiority of the iron resulting from the use of hot blast, is occasioned by the greater heat of the furnace, a fact I am by no means prepared to admit.

148. That the temperature of the furnace is higher, where hot blast is used, than with cold, seems always to have been regarded as a position so clear and self-evident as to require no demonstration—and if erroneous, as I believe to be the case, it has certainly been a great stumbling-block in our path towards attaining correct ideas of the process of iron manufac-

* Foremost among these must be considered an adequate supply of oxygen to burn off the sulphur, phosphorus, and arsenic, and preserve the silicic acid, lime, and magnesia from deoxidation, and thus prevent the formation of *metallic alloys*, or if this (probably correct) term be objected to with regard to the first-named substances, say in their case, sulphurets and phosphurets.

ture, with the consequent improvement in the art, which might therefrom be expected.

149. At the temperature to which the blast is heated, air is more than doubled in volume; therefore, there will be double the number of atoms of oxygen in the same space, when the blast is cold, and consequently a much more rapid evolution of heat from the surface of the carbon exposed to the direct action of the blast; the stroke also will be of double the weight, producing a more rapid disentegration of the carbon, and a more thorough dissemination of it amongst the other materials.

150. The effect of the cold blast on the surface of the ore will be refrigerating, and the same must be said of its impact on the limestone flux, but I see no reason to conclude that the refrigerative effect in the last two instances, more than counter-balances the increased temperature evolved by the surface of the carbon. Therefore immediately before the *tuyères*, at the point where the most perfect fusion takes place, I see no reason for believing that the temperature of a hot blast furnace, exceeds that of a cold blast, but rather the reverse; inasmuch as I conceive, that a larger *quantity* of oxygen will combine with carbon, in a given *space* within a given time, in the latter furnace, than in the former: a *sufficiently* larger quantity in fact, to more than counter-balance the additional initial heat of the air, *before* the expansion* due to the combustion, and therefore necessarily ensuing *subsequently* to it, has taken place.

* An atmosphere of 4,000° condensed to ⅛th of its volume (or what is the same thing gaseous products of combustion at that point of expansion where they have only reached ⅛th of their ultimate bulk) will have a temperature of about 7000°, and when condensed to half their ultimate volume a temperature of about 5000°. Here we get at the *cause* of the great heat of flame, and the superiority of the direct action of flame, or the radiant heat from an ignited surface of carbon, for communicating heat (e.g. raising steam) over products of flame *after expansion*, see on this subject, paragraphs 109 & 110.

Air of 60° has its volume increased to

Double at . . .	568°	Fivefold at . . .	2092°	Eightfold at . .	3616°
Threefold at . .	1076°	Sixfold at . . .	2600°	Ninefold at . .	4124°
Fourfold at . .	1584°	Sevenfold at . .	3108°	Tenfold at . . .	4632°

151. *After* expansion has taken place, the temperature of the hot blast furnace will of course exceed that of the cold blast furnace at the same point, by the excess of the initial temperature of the air, and the same may be said of any two localities in the furnaces where the same degree of expansion exists. When the carbonic oxide zone is reached, although the difference remains the same, yet from the great diminution of temperature, the *disproportion* between the heat of the two furnaces becomes very marked. Say coke in forming carbonic acid imparts to the combining equivalent of air 4058°, suppose the temperature of air 42°, this will give an atmosphere of 4100°; assume that the volatilization of the carbon, necessary to transform carbonic acid, into carbonic oxide, absorbs 60 per cent. of this heat, and we have for the carbonic oxide zone, a temperature in a cold blast furnace of 1640°, and in hot blast furnace 1640° + the initial additional temperature of the air, say 560° = 2200° or $\frac{1}{3}$ more, a difference sufficient to make it not improbable, that the chemical action of the carbon on the ore, may be greatly modified by it. Indeed the *stewing* of the minerals with their surfaces in a semi-melted state, in an atmosphere of carbonic oxide, with perhaps the addition of the fumes of sulphur, phosphorus, and arsenic, for a considerable period before their descent before the *tuyères*, is a vastly more plausible reason for the inferiority of hot blast iron, than the hitherto-received-without-being-questioned theory, which assigns it to the increased heat of the furnace, at the point of fusion.

152. The circumstance that hot blast furnaces work faster than cold, has been supposed to be quite conclusive as to a higher temperature being attained by them; a little examination will however shew that the fact affords no foundation for such an inference. If we assume that the perfect fusion of the minerals of a blast furnace requires a heat of 4000°, that the temperature of the point of most intense heat in the vicinity of the *tuyères* in each description of furnace is the same, viz. 5,000°; since the minerals will in the hot blast furnace, approach this

point at a temperature 560° higher than they will approach the same point in the cold blast furnace, and consequently will require 560° less additional heat imparted to them, to raise them to the temperature of 4000°, their melting, will as a matter of course be more quickly performed in the former furnace, than in the latter; and thus this supposed decisive fact in favour of the higher temperature attained by the use of the hot blast, is satisfactorily explained without leaving any difficulty behind it.

153. In considering the manufacture of iron with reference to economy of fuel, the most striking thing which forces itself upon the attention, is the fact, that whilst the two great processes of iron making, viz. the separation of the iron from the ore in the blast furnace, and its decarbonization, and kneeding to develop fibre, in the boiling furnace, each requires for its performance, and *is best performed by*, one of the two constituents into which coal is resolvable, taken singly; viz. the revival of the iron, by the solid carbon or coke, and the operation of boiling, or puddling, by the gaseous carburetted hydrogen; yet strange to say, instead of separating the constituents of coal before using, and employing each for the operation for which it is best suited; we use it in its raw state for both operations, not only wasting one constituent in each process, but absolutely producing inferior results. For the gaseous portion of the coals used in the blast furnace,—which if separated and purified, would suffice to make all the pig-iron produced by the furnace, into puddled-iron, of a quality very superior to that made by raw coal,—exercises in the blast furnace a deteriorating effect on the quality of the iron produced. Thus all the coal at present used in puddling is wasted, with the result of obtaining an inferior description of iron.

154. My notions of attainable perfection demand, that iron should be manufactured as follows :—the coal should be coked by the waste heat from the furnaces, and set apart for use in the blast furnaces, having previously as before described, had its pores impregnated with a preparation composed with reference to its power of combining, and forming an easily fusible cinder with

the ashes of the coke on the one hand, and the foreign matter in the ore on the other.

155. The gaseous products of distillation after being purified from sulphur, and also from phosphorous, and arsenic if present, should be devoted to the process of puddling, for which they are for many reasons much better adapted than raw coal; in the first place, the dust and fine cinders carried over from the grate, become mixed with, and injure the iron, and the same may be said of various volatile products of the coal; in the second place, the operation of puddling consists of three different stages, during each of which the iron requires a modification in its treatment, which the present puddling furnace is powerless to supply; in fact no prompt nor *adequate* power of control is possessed by the workman over it, even for simply exalting its temperature, and as far as the scientific performance of its functions is concerned, it must be regarded as a barbarous machine which ought long since to have been superceded.

156. In the first stage—that of melting—an intense heat, with no excess of oxygen, will save both time and iron, although it is not so absolutely indispensable in this stage as in the third.

157. In the second step of the process—that of decarbonization, or refining—an excess of oxygen is wanted, and the addition of the vapour of water is also often beneficial, since it has the power, not only of accelerating the decarbonization of the metal, but also of carrying off large quantities of silicic acid, in a volatile form,* the effect of which in increasing the *yield* (inasmuch as the silicic acid would otherwise form a silicate of iron, and carry its base into the cinder) is sufficiently obvious.

158. During the third stage of the process—that of kneading the decarbonized iron into a tenacious, fibrous mass—an excess of oxygen passing is productive of great loss, from the waste it occasions by oxydizing the pure malleable iron, now no longer

* An instructive example of the law, that non-volatile bodies may become volatile by mixture with volatile ones.

covered by the cinder. From the circumstance however of a great heat being necessary (requiring a clear fire) during this stage, particularly at its termination, just before the iron is removed from the furnace to go to the squeezer, it is impossible to guard against a surplus of oxygen being present,—such is, in fact, always the case under the present system,—a considerable loss is unavoidable, and may be considered a perfectly normal result of the operation as carried on in the existing furnaces.

159. Let us compare with this narration of the inefficiency and unavoidable defects of the present furnace, the advantages placed within our reach by the judicious application of gas.

160. Suppose a furnace constructed as follows: let the end of the furnace be formed of an iron box, divided vertically (and transversely as regards the body of the furnace) into three divisions; let the outer one be connected with a reservoir of gas under pressure, the middle one with a similar reservoir of air; let a series of tubes (with a slight downward inclination) lead from each of these chambers, through the inner chamber, into the furnace; let the inner chamber be supplied with water, to prevent the melting of the tubes or *tuyères*. Since the quantity of an elastic fluid, which passes in a given time, through a pipe of a certain diameter, under a given pressure, is easily ascertained, we thus possess it in our power to apportion the quantity of air and gas to each other with the greatest nicety, according to our varying requirements.

161. The pipes leading from the main reservoirs of gas and air to the chambers of the furnace, should each be furnished with a throttle valve, the handle of which should form the index to a dial, graduated to 100° subdivisions; and the size of the pipes and the valves should be so arranged, that when the indexes pointed to the same figures on the dials, the respective quantities of air and gas passing, should be the exact combining equivalents of each.

162. As it would be desirable to have a surplus heating power, beyond that demanded for ordinary working, for extra-

ordinary occasions, such as getting up the heat after the furnace had been allowed to get cold, &c., we will suppose, that upon charging with fresh iron, the hands of both dials are placed at 75, for the first stage of the operation. The inclination of the *tuyères* driving the flame downwards directly on the iron, it will be melted and brought to the proper point of fluidity, in about half the time occupied by the present furnace, where the axis of the draught being horizontal, and the iron lying completely below it, by far the larger portion of flame darts over it, and enters the flue without having at all impinged on the iron. In fact, the difference in the mode of operation of the two furnaces, is the difference between placing a body at the point of the flame of a blowpipe, and placing it at the exterior of its under side.

163. The next stage of the operation—that of refining, or decarbonization—requires a surplus of oxygen to be present, to obtain which, the workman moves the index of the air pipe, say to 90 (the index of the gas pipe remaining stationary at 75), and turns on in addition, if thought desirable, a supply of steam into the air chamber, to pass, with the air, into the working chamber. That such a furnace would be a better instrument for refining iron than our present one, cannot admit of a doubt, whilst it is equally unquestionable that it would do its duty in less time.

164. During the third stage of the operation, a very intense heat is required, particularly just at the latter end, whilst, at the same time, it is of vital importance—to prevent the waste of the now undecarbonized and exposed iron—to ensure that a surplus of oxygen be not present. Let the workman set the index of the gas pipe at 95 (the air pipe index remaining, as before, at 90),—thus guarding against the possibility of any free oxygen reaching the iron through imperfect mixture, by supplying a slight excess of carburetted hydrogen,—and both conditions will be fulfilled.

165. In short, whatever the requirements demanded by the progress of the operation, this furnace places at our disposal the means of fulfilling them *instantly* and *completely*, furnishing in

this respect, a complete contrast to the imperfect means of control offered by the existing furnace; nor must it be forgotten, that it presents us with all these advantages, at the cost of the gaseous products of the coal, now wasted in the blast furnace.

166. Having thus briefly reviewed the subject of puddling, and endeavoured to show that great improvements may be made in our present arrangements, with regard both to economy of fuel, and the production of a superior quality of iron, I will now offer a few observations on blast furnaces.

167. In the figures which I employ with regard to the *theoretical* composition of the gases issuing from a blast furnace, as deduced from the composition of the fuel used, I shall principally rely upon the data on the Alfreton coal and furnaces, contained in the elaborate report on blast furnaces, presented to the British Association in 1845, by Dr. Lyon Playfair and Professor Bunsen; since the methods of eudiometric analysis resorted to by these accomplished chemists, appear superior in accuracy to those of previous observers. It is to be regretted that so much care in analysis, should not have been associated with equally unexceptional methods for obtaining the samples of gases from various depths of the furnace. A tube of only 1 inch in diameter, can never be considered a satisfactory test of the *average* composition of the gases, particularly in furnaces where, as in the instance of the one on which they experimented, the materials are thrown in in such large masses that some of the pieces of coal were nearly of the bulk of a cubic foot. See on this subject, Ebelman, *Annales des Mines*, 1851.

168. A blast furnace may be viewed as an apparatus in which a series of chemical operations take place, viz., that of distillation in the upper portion, and those of cementation, reduction, and fusion, at gradually increasing depths. Certain materials are thrown into the mouth of the furnace, which, after undergoing certain transformations effected by their natural affinities, and the oxygen of the blast, aided by heat, either present themselves

in the hearth as pig iron and slag, or issue in a gaseous form from the top of the furnace. It is evident, that if we know the composition of the raw materials employed, the changes they undergo, and what portions of these materials are delivered at the hearth, we can deduce the composition of the gases issuing from the top, and constituting the remaining product.

169. Observation has established, 1st, that the oxygen of the blast is all consumed in the immediate vicinity of the *tuyère*; 2ndly, that in hot blast furnaces, the carbonic acid zone is of very limited extent, this gas being found entirely converted to carbonic oxide within about 3 feet from the point of the *tuyère*; 3rdly, that the coal loses all its gaseous products of distillation much above the point at which its carbon combines with the oxygen of the blast.

170. Each charge at the Alfreton furnaces consists of 420lbs. of calcined ore, 390lbs. of coal, and 170lbs. of limestone; and the product of iron resulting from one charge is 140lbs.

100 parts of the coal contained*—

		Parts of water capable of being heated 1° C. by the combustible.
Carbon	64·548	516,384
Carburetted Hydrogen	6·638	99,570
Carbonic oxide	1·602	3,660
Carbonic acid	1·139	
Bi-Carburetted Hydrogen	0·513	6,156
Hydrogen	0.370	13,320
	Total	639,090
Contributed by the carbonaceous portion		516,384
Contributed by the products of distillation		122,706

* The coal contained, in addition, ·253 of sulphuretted hydrogen, and ·163 of ammonia, omitted in the text from their heating power being too trivial to claim attention, and also because the air contained in the crevices and pores of the materials supplied, (for the effect of which no allowance is made in the report,) must more than counterbalance any addition made to the

171. Since cast iron contains 3·3 per cent. of carbon, there will be 1·18 abstracted from each 64·548 parts of carbon for this purpose, leaving 63·368 parts of carbon to undergo combustion.

172. This carbon, as has been already stated, becomes converted into carbonic oxide, by combining with the air of the blast, at a short distance above the *tuyère*, the product being—

Nitrogen	295·716
Carbonic oxide	147·858

The quantity of cast iron produced by 100 parts of coal, is 35·8 = 34·62 of pure iron, to effect the deoxidation of which,

heating power of the gases, by the presence of these two substances. For similar reasons, I have taken no account of any slight increase which may be produced in the heating power of the escaping gases, by the change wrought in those portions of the products of the distillation of coal, which, from being disengaged at a considerable depth, are subjected to a decomposing heat in their passage upwards; and upon which modifying influence, much more stress is laid in the report above alluded to, than I think the subject is entitled to claim. It observes, "the upper layers of coal, limestone, and iron, being cold, cause a condensation of the water and tar, both of which drop back upon the red hot coals in the inferior layers, and become partly decomposed into hydrogen and carbonic oxide gas, whilst another part of the tar is broken up into hydrogen, light carburetted hydrogen, and charcoal. The portions escaping this decomposition are condensed anew by the cold layers above, and finally themselves suffer change." Now, granting that this condensation can take place (which, except momentarily, with reference to the materials just thrown into the furnace, I deny), since it is certain that materials cold enough to condense these vapours, on the one hand, and hot enough to decompose them on the other, could not be reposing in layers in very close apposition to each other, we are required to suppose that these condensed liquids trickle and drop from stone to stone for many feet, till at length they alight on one hot enough to effect their decomposition; pertinaceously preserving their fluidity all the time, and refusing to vaporise, although resting on hot bodies, and swept by a current of highly heated gas, so imperfectly saturated with moisture, as to be capable of licking up ten times the quantity of liquid. It may be safely pronounced that nothing of the kind ever does, or can, take place in a blast furnace; and if the small portion of the vapour of water which finds its way to a sufficient depth to come in contact with ignited carbon is decomposed, as would unquestionably be the case, a much larger portion passes off with the gases in the form of vapour, deteriorating their combustible value.

the carbonic oxide must combine with 14·83 of oxygen, and have 25·952 of its parts changed into 40·782 of carbonic acid.

173. The quantity of limestone, added to 100 parts of coal, contains 18·7 parts of carbonic acid, which is evolved from the furnace with the other gaseous products, giving as a result, for the composition of the gases issuing from the mouth of the furnace—

Nitrogen	295·716
Carbonic oxide	121·906
Carbonic acid	40·782
Ditto do. (from lime) . . .	18·700
Total . . .	477·104

added the products of the distillation of 100 parts of coal.

174. Hence it appears that we shall obtain the composition of the gases from the furnace, if, to the products of the distillation of any given quantity of coal, we add the carbon of the coke formed from that coal (minus the portion entering the iron), plus the quantity of air necessary to form with this carbon, carbonic oxide,—plus the oxygen of the ore (which converts a portion of this carbonic oxide into carbonic acid), and plus the carbonic acid evolved from the limestone.

175. From the preceding data, the composition of the gases evolved for each 100 parts of coal is found to be—

			Total of each.	In 100 pts.
	Nitrogen	295·716	295·716	60·677
	Carbonic oxide	121·906	123·508	25·342
	Carbonic acid	59·482	60·621	12·439
From distillation of coal.	Carbonic oxide	1·602		
	Carbonic acid	1·139		
	Carburetted hydrogen . .	6·638	6·638	1·362
	Bi-carburetted hydrogen .	0·513	0·513	·105
	Hydrogen	0·370	0·370	·075
	Total . . .		487·366	100·000

176. Since the whole of the products of the distillation of coal escape unburnt, our task in finding the duty performed by the fuel, is narrowed to an examination of the changes undergone by the carbonaceous portion.

177. I shall assume that carbon, in becoming $C\,O$*, developes $\frac{1}{3}$ part of the heat developed by it in becoming $C\,O_2$, this being about the mean of the figures given by the three observers, Dulong, Andrews, and Grassi, *(see note, page 5)*.

Of the total carbon in the fuel	64·548	
There enters the iron	1·18	
Leaves the furnace as carbonic acid . . .	11·1225	
Therefore discharges its full duty . . .	12·3025	
Leaves the furnace as carbonic oxide . . .	52·2455 having *apparently* discharged only $\frac{1}{3}$ of its duty.	
	Carbon.	
Full duty of	12·3025 =	98,420
$\frac{1}{3}$ duty of	52·2455 =	139,321
	Total . . .	237,741

178. If we subtract this sum from the full duty of 100 parts of coal, viz. 639,090, the remainder, 401,349, shows the duty capable of being performed by the gaseous products escaping from the furnace. Then,

as 639,090 : 237,741 : : 100 : 37·2

whence it appears that this amounts to 62·8 per cent., leaving 37·2 per cent. for the *apparent* duty realised.

179. These figures differ so greatly from the statements of Dr. Playfair in the report before alluded to, that I feel it necessary to advert to the subject, the more particularly, as from the reputation of the individual from whom they emanate, and the authority of the publication in which they appear, they are calculated to foster (as I know they have already produced) great delusion with reference to this important question.

180. The report says, "Hence follows the remarkable conclusion, that in the furnaces of Alfreton, not less than 81·54 per cent. of the fuel is lost in the form of combustible matter still fit for use, and that only 18·46 per cent. of the whole fuel is realised in carrying out the processes in the furnace."

181. Thus it appears that the figures given by Dr. Playfair, restrict the duty performed by the fuel, to just half the amount

* For an explanation of these symbols, see page 85.

which my calculations have assigned to it. The difference in the results at which we have arrived, is easily traceable to the difference in the principles which have guided our mode of procedure, and to the difference in the ratio we assume, that the portion of heat developed by carbon in becoming carbonic oxide, bears to the full amount it is capable of furnishing, when it unites with 2 atoms of oxygen; on this latter point see par. 177. and note at page 5. To estimate the duty performed, Dr. Playfair simply takes the amount of nitrogen, deduces the quantity of oxygen which accompanied this into the furnace as atmospheric air, and then calculates the heat which would be evolved by the union of this oxygen with carbon to form carbonic oxide. It is evident that such a method altogether ignores the duty done by the 1·18 of carbon, which combines with the iron and descends with it into the hearth, and also the important service towards "carrying out the processes in the furnace" rendered by the 11·1225 of carbon, which, in the form of 25·952 of carbonic oxide, separates 14·83 of oxygen from the ore, and becomes converted into 40·782 of carbonic acid in so doing. The latter process, the report observes, is attended with a thermo-neutrality, but surely this can be no valid reason for not reckoning it with the realised duty of the carbon. If we revive iron by placing some iron ore in a crucible, in conjunction with charcoal, and then subjecting the vessel to the heat of a furnace, can any one be found to contend, that the duty performed by that portion of charcoal which combines with the iron, and by that other portion which removes its oxygen by combining with it, is any less real, than that achieved by the charcoal of the furnace, in contributing the necessary temperature? In fact,—since the *whole* of the carbon which combines with the oxygen of the ore, is absolutely required for this purpose, and not a particle can be dispensed with, whilst on the contrary, it might be a question whether some of the carbon in the furnace is not burnt in furnishing superfluous heat,—many would be disposed to accord the precedence in importance and indispensability to the services of the former—and to deny to the function it performs, the title of realised duty, certainly indicates a singular inversion of ideas.

182. It may have been observed, that in treating on the 52·2455 parts of carbon which left the furnace as carbonic oxide, I spoke of its having *apparently* discharged only $\frac{1}{3}$ of its duty; and however unexceptionable the mode of estimating its duty adopted, may, on a superficial view appear, I am prepared to show, that it inadequately represents the real services rendered by the carbon to the processes of the furnace, and that if the various parts played by the fuel, are separately scrutinized, and their results analyzed with exactitude, the duty *performed* by the carbon will be found to be much more considerable. Since the whole of the atmospheric oxygen entering with the blast, is converted into carbonic oxide at a comparatively short distance above the *tuyère*, affording in this form an ample supply of carbon to effect the deoxidizing process of the furnace, without the absorption of any uncombined carbon for this object; and since we know, that when we form carbonic oxide from carbonic acid, by supplying the latter with another equivalent of carbon, exactly half the amount of carbon in the product, must have previously been in combination with 2 atoms of oxygen, as carbonic acid, we are enabled to pronounce that the combustion of the carbon in the furnace takes place as follows:—Deducting the 1·18 of carbon which enters the iron, precisely one half the remainder is converted to carbonic oxide in the zone of transition which *must* exist between the carbonic acid zone (or zone of fusion), and the carbonic oxide zone, where this conversion is complete; whilst the remaining half descends before the *tuyère*, where, by its conversion to carbonic acid, it furnishes the intense heat necessary to produce perfect fusion of the refractory minerals employed.

183. The fact, that *subsequently* to performing this service, the 31·684 parts of carbon, in combination with 84·49 of oxygen as carbonic acid, yields up half its oxygen to an additional portion of 31·684 parts of carbon, with a great thermometric

loss, must not blind us to the amount of duty which it has previously *actually accomplished*, and which, if it left the furnace immediately afterwards, before its transformation into carbonic oxide, would be unhesitatingly admitted. Does it injure or retard the processes of the furnace, in its subsequent passage through it, that at its final exit, we curtail its claims for services previously accomplished? So far from doing so, it increases our obligations for work performed, by separating 14·83 of oxygen from the ore, and we repay the additional service, by paring down its duty into simply yielding the measure of heat due to the formation of carbonic oxide.

184. Estimated according to this more accurate and precise view of its true functions, the duty performed by the fuel in a blast furnace, will be as follows:

Of the total carbon in 100 parts of fuel = 64·548	
There enters the iron	1·18
Carbon (as simple carbon) burnt to CO_2 before *tuyère*	31·684
Consequently discharges full duty	32·864
Carbon (as CO) becomes CO_2 in separating 14·83 O., consequently discharges $\frac{2}{3}$ duty	11·1225

The full duty of 32·864 of carbon is 262,912 and $\frac{2}{3}$ duty on 11·1225 is 59,320, making together 322,232 for the duty performed by the carbon, which sum is to 639,090 the whole duty of 100 parts of coal, as 50·4 is to 100; consequently, the duty performed by the fuel is 50·4 per cent., or nearly 3-fold what has previously been assigned to it—and that this is the proper way of estimating the duty of the carbon, is abundantly plain and clear, and once pointed out, will I think be felt to admit of no dispute. That the duty done by the fuel should be 50·4 per cent., and that capable of being evolved from the escaping gases 62·8 per cent., making together the sum of 113·2 per cent., may at first sight appear a discrepancy, but when more narrowly examined, the apparent anomaly vanishes. A given quantity of carbon as CO_2, at a temperature sufficient to convert carbon into CO, will, by so doing, form a compound capable of developing by combustion 33·3 per cent. more heat than the carbon so converted. In one case we have 100 parts of carbon (as simple carbon), capable of developing 100 parts of heat; in the other, 200 parts of carbon as CO, capable of developing 133·3 parts of heat, according to the law that $\frac{2}{3}$ of the whole heat capable of being developed by carbon, are developed when CO becomes CO_2. In the case of the blast furnace before us for consideration, the difference will be, the difference between the heat-developing power of ·31·684 of carbon (as simple carbon) converted to CO_2, and 63·368 of carbon (as CO) converted to CO_2 = 84,490·66 units, and 639,090 is to 84,490·66 as 100 to 13·2 —the amount of overplus.

185. Supposing 100 parts of carbon burnt to CO_2 in a common reverberatory furnace, and the full duty thus obtained applied in the most advantageous manner to the processes of the furnace—suppose further, that instead of the products of combustion being discharged at once into the atmosphere through the stack in the ordinary way, they are passed through a shaft filled with carbon, where they combine with another 100 parts of carbon, and thus become converted to CO. What *would* be said to a plan for estimating the duty of the fuel, which took the gaseous products discharged as CO, found them to be capable of generating 133·3 parts of heat, and hence affirmed that the duty previously performed by the fuel in the furnace, must be only 66·6 per cent. Everybody would in this case cry fallacy; yet, as far as the principle involved is concerned, the procedure presents an exact parallel to the mode of estimating the duty of the fuel in blast furnaces, adopted in the report before alluded to, with the exception, that in the case of the latter, the fuel still performs *additional services after* its conversion to carbonic oxide, making the inaccuracy so much the greater.

186. Although we have found the amount of duty performed by the fuel in blast furnaces to be much more satisfactory than had previously been stated, amounting to 50·4 per cent. instead

of only 18·46 per cent., yet the heat capable of being realised from the escaping products, amounting to 62·8 per cent. on all the fuel consumed, is still a loss which it would be most desirable to curtail, either by diminishing the *consumption*, by increasing the *duty* of the fuel, or by turning the waste products to some useful account.* Their value as an article of fuel, depends less upon the whole quantity of heat they are able to afford, than upon the *temperature* they are capable of generating, since it is this which must determine to what objects they are applicable, and the extent of their sphere of practical utility. To ascertain the temperature capable of being attained by the combustion of these gases, we must determine their heating power from their composition, and then ascertain the specific heat of the products resulting from their combustion.

Composition of furnace gases.		No. of degs C. 1 part of water would be raised by the combustibles.	Result of combustion.	Totals.	Ditto reduced to 100 parts.	Specific heat.
N	295·716			652·18 N	68·9644	·27
CO_2	60·621			274·57178 CO_2	29·0344	·22
CO	123·508	282215°	194·084 CO_2 247·016 N			
H_2C	6·638	99570°	14·9355 HO 18·2545 CO_2 92·9320 N	18·925 HO	2·0012	·847
H_2C_2	0·513	6156°	0·65957HO 1·61228CO_2 6·156 N			
H	0·370	13320°	3·330 HO 10·36 N			
Totals	487·366	401261°		945·67678	100·0000	·267

Then $\frac{401261}{945{\cdot}67678 \times {\cdot}267} = 1589°$ C. or 2900° Fahr. the temperature

* For particulars of the best methods of taking the waste gases from blast furnaces, see an able paper on this subject by Mr. S. H. Blackwell, in the *Proceedings of the Institution of Mechanical Engineers*, for October, 1852.

these gases are theoretically capable of yielding on combustion. This degree of heat is amply sufficient for raising steam, heating the blast, manufacturing gas and coke, burning bricks or lime, and a variety of other operations*, but is not adequate to be employed with advantage for the manufacture of iron, as was once supposed,—an erroneous idea, which has led to the waste of much capital in abortive experiments, the success of which, a more accurate knowledge of the subject, would have seen to have been *à priori* impossible. In the report before alluded to, it is stated that the temperature capable of being attained by the combustion of these gases is 3,083°, that by using a blast sufficiently heated, this could easily be raised to 3,632°; and that since cast iron

* I believe one of the most feasible and practically useful applications of the heated gases, would be the desiccation of the air with which the furnace is supplied, which might be effected by their agency in many ways. The injurious effect and loss, produced by the moisture in the air in hot and damp weather, being *much* greater than is commonly suspected. To attain this object, let two beds of muriate of lime be prepared, each resting on a tubular iron grating, or coil of pipe, let the air for the blast engine be drawn through, or over, these beds alternately, and in the intervals, let a portion of the heated gases, or, if necessary, a portion of the products of their combustion, be passed through the coil of pipe of the bed not in use. So may the blast furnace be constantly supplied with desiccated air at a trifling expense, and its operations be rendered independent of atmospheric vicissitudes. The result would be a saving of fuel, an increase in yield, and an improvement in the quality of the iron; in fact, a making *constant*, that state of advantageous working, which now exists only for a few weeks in each year during the frosty weather of winter.

Air saturated with moisture contains at—

Degrees Fahr.	Grains of water in each cubic ft.	Degrees Fahr.	Grains of water in each cubic ft.	Degrees Fahr.	Grains of water in each cubic ft.
10	1·11	40	3·09	70	8
20	1·58	50	4·28	80	10·81
30	2·21	60	5·87	90	14·5

Now, 4000 cubic feet of air per minute=240,000 cubic feet per hour=5,760,000 cubic feet per day, is a common quantity for a blast furnace to consume, and therefore, if we suppose the state of saturation of the air to be ·75, such a furnace will receive per day in the air of the blast, 1364 lbs. avoirdupois of water, when the temperature is 30°, and 4,937 lbs, or nearly four times the quantity, when the thermometer stands at 70°.

melts at 2,192°, it follows that the gases, when burned with hot air, would yield a temperature more than sufficient to melt iron. For the futility of the use of hot air for such an object, I refer the reader to the remarks on *attenuated* flame, pars. 110 and 112. In the next place, the temperature *attainable* by the gases is *over*-stated, and that required for melting cast iron *under*stated, the most reliable observations, those of Daniel, fixing its melting point at 2,786°. However, the very fact of there being a difference of 600° in the melting point assigned to cast iron, by different observers, shows how unsatisfactory are arguments founded on such theoretical deductions, when compared with the very conclusive evidence on the subject lying open before us, in the results attending the use of coal. Now we find that coal, the heating powers of which are vastly superior to the gases, only just generates sufficient heat for the processes of iron making; any impairment of the heating power of the furnace, from atmospheric vicissitudes, or errors of construction, being at once followed by deterioration of its working capability, and waste of iron. And when it is considered that 1 cwt. of iron is worth more than a ton of coal, it will be readily understood, that saving the latter at the expense of the former, is, as regards the pocket of the manufacturer, the saving of a negative quantity. The fact is, that to estimate the temperature we practically attain in our reverberatory furnaces, we must deduct from 20 to 25 per cent. from the theoretical value of the fuel, to allow for the imperfect combustion of the gases on the one hand, or the excess of air on the other; for when it is reflected, that the mixed stream of air and gases, darts through a reverberatory furnace with a velocity of 40 feet per second, passing through the working chamber of a puddling furnace in about $\frac{1}{8}$ of a second, we have no difficulty in understanding, that unless a prejudicial excess of air be admitted, some portion of still uninflamed gas must pass into the region of the flues. In steam boiler furnaces, where an excess of air is not so injurious, it is found advisable to admit $\frac{1}{5}$ more air than the combining equivalent; for though the excess of uncombined air thus necessarily constantly passing off, must rob the furnace of a great deal of heat, yet it is found, that if it be attempted to lessen the quantity, the result is injurious; the diminished amount of combustion that ensues from the increased quantity of gas which passes off unburnt, producing a greater loss of heat, than that previously abstracted by the excess of air.

188. The practical value of the furnace gases for fuel, is much diminished in those localities, where, as in some parts of Staffordshire, a superabundant supply of slack (found in getting the good coal) can be obtained for burning under the steam boilers, at an almost nominal price, from its insufficiency for other purposes.

189. In those cases where, from the nature of the ore or fuel, or both combined, economy requires the use of the hot blast, and the quality of the pig metal resulting, becomes much deteriorated in consequence, it becomes a question deserving attentive consideration, how far subjecting the iron to some intermediate treatment between the blast furnace and the puddling furnace, may not be desirable,—some process which should effect cheaply, and at little loss beyond the removal of the actual impurities, what is now accomplished with such a great waste of iron and fuel, in the almost obsolete refinery. It appears to me, such a desideratum might be attained, by the melted metal on issuing from the blast furnace, being filtered through a bed of ignited charcoal, the pores of which had been charged with fluxes of such a character, as to form with the impurities contained in the iron, a neutral cinder. In the present refinery, no artificial flux being used, if silicon is present, it is separated at the expense of a loss of iron, forming as fast as it is oxidized, a silicate of the protoxide of iron, for want of having a stronger base presented to it. After being refined, the iron should be transferred still melted to the puddling furnace, to receive its fibre; for unless some benefit can be shewn to accrue to the process, from the iron being allowed to cool, compelling an expenditure of fuel for its re-melting, such unnecessary waste

should be avoided: in short, the requirements demanded by a rigid economy of fuel, can never be fulfilled, till the period arrives, when the iron will not be allowed to cool, from the time it issues from the blast furnace, till it passes the rolls, a puddled bar.

190. I shall doubtless be told, that such refinements and niceties as I propose to introduce, are unnecessary superfluities. This however is the language of ignorance and slothfulness, for improvements are never superfluous to any other eyes. The machinery of a cotton mill is doubtless a "*prodigiously* complicated apparatus, when compared with a distaff and spinning-jenny, but then its results are *more* than "*prodigiously*" greater. In short, the whole question is one of *degree;* and where the advantages to be obtained, greatly preponderate over the trouble incurred by the additional appliances necessary for their attainment, it rests not in the power of ignorance and supineness, to prevent their ultimate adoption. It is unquestionable, that the manufacture of iron has hitherto borrowed less from science, and is in a ruder and more barbarous state, than our other manufactures, and it is equally unquestionable, that such a state of things will not be allowed to continue. Why are "refinements and niceties," introduced, carried out, and adopted, in other departments of production? Is it to gratify a longing for the ideal in those engaged in them, or as a question of £. *s. d.*? In short, when we view the keen spirit of enterprise and competition which leads manufacturers in other departments, to seek to increase their profits by every expedient for cheapening production, which the improved chemical and mechanical knowledge of the day places within their reach, it is puerile to suppose that the iron trade is to prove an isolated exception to a general rule, and remain exempted from the operation of the same principles. The shadow will not tarry on the dial for the sluggard, and those who will not read the signs of the times, but choose to persist in working by the rule of thumb, will be taught its insufficiency by their balance sheets.

EXPLANATION OF THE SYMBOLS USED IN THE DIAGRAMS AND TABLES WHICH FOLLOW.

The essence of a chemical compound is, that its constituents always bear a definite proportion, by weight, to each other; and the most important discovery in modern chemistry has been the law, that bodies unite *only* in these definite proportions (termed their atomic weights), or in simple multiples of them.

Thus the proportions, by weight, in which oxygen and nitrogen combine with each other, and with all other substances, are 8 parts of the former and 14 of the latter.

Atoms.		Weight.		Atoms.		Weight.		Atomic weight.
2	nitrogen	28	are present with	1	oxygen	8	in atmospheric air	. . 36
1	"	14	combined with	1	"	8	forms nitrous oxide	. . 22
1	"	14	"	2	"	16	forms nitric oxide	. . 30
1	"	14	"	3	"	24	forms hyponitrous acid	38
1	"	14	"	4	"	32	forms nitrous acid	. . 46
1	"	14	"	5	"	40	forms nitric acid	. . . 54

and no compound with intermediate proportions can exist.

Chemists have agreed, that the first letter of the names of the elementary bodies, shall designate, not only the elementary body, but also one combining equivalent, by weight, of such body. The atomic weights of hydrogen, oxygen, nitrogen, and carbon, are 1, 8, 14, and 6, respectively.

H designates therefore, not merely hydrogen, but 1 part by weight, of hydrogen.

O not merely oxygen, but 8 parts by weight, of oxygen.

N 14 parts, by weight, of nitrogen.

C 6 parts, by weight, of carbon.

C O one equivalent of each of these bodies; that is to say, 6 parts, by weight, of carbon, and 8 parts, by weight, of oxygen, constituting carbonic oxide.

CO_2 one equivalent of the former body and two of the latter; that is to say, 6 parts, by weight, of carbon, and 16 parts, by weight, of oxygen, constituting carbonic acid.

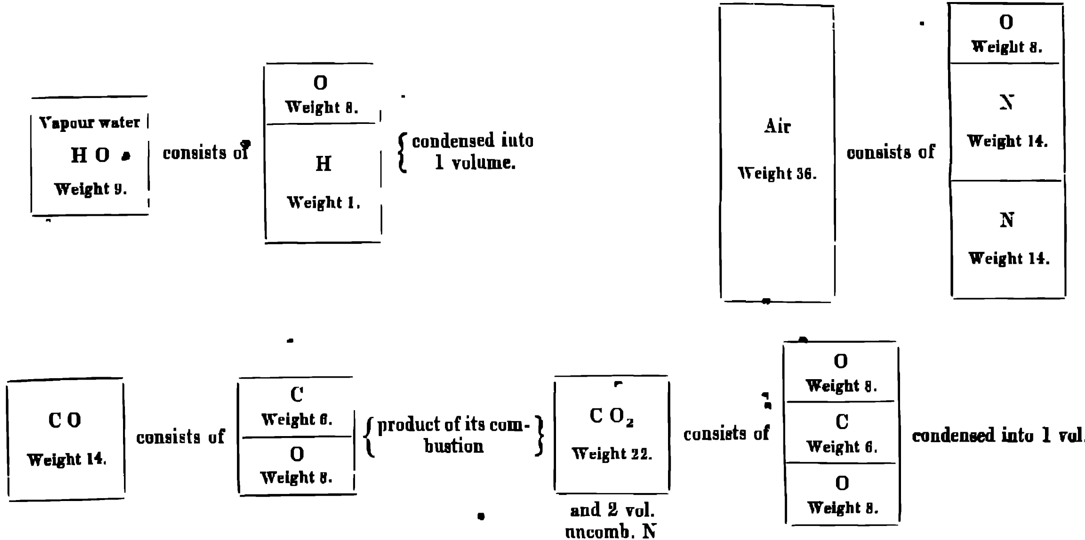
H O 1 part, by weight, of hydrogen, and 8 of oxygen, constituting water.

H_2C 2 parts, by weight, of hydrogen, and 6 of carbon, constituting carburetted hydrogen.

H_2C_2 2 parts, by weight, of hydrogen, and 12 of carbon, constituting bicarburetted hydrogen.

DIAGRAMS ILLUSTRATIVE OF COMBUSTION.

[The areas show the relative size of the gas volumes. Thus, 1 atom of oxygen gas, weight 8, occupies only half the space of 1 atom of hydrogen, weight 1: consequently for equal volumes, the proportion by weight, between these two gases, (or in other words, their specific gravity) is as 1 to 16.



H_2C Weight 8	consists of {cond. into 1 vol.	H Weight 1. / C Weight 6. / H Weight 1.	{product of its combustion}	HO Weight 9. / HO Weight 9	and	CO_2 Weight 22.	and 8 vol. uncomb. N.
H_2C_2 Weight 14.	consists of {cond. into 1 vol.	H Weight 1. / C Weight 6. / C Weight 6. / H Weight 1.	{product of its combustion}	H O Weight 9. / H O Weight 9.	and	CO_2 Weight 22. / CO_2 Weight 22.	and 12 vol. uncomb. N.

[For an explanation of the Symbols, see p. 85.]

ANALYTICAL TABLE

OF THE POWERS OF VARIOUS COMBUSTIBLES.

Name of combustible.	Specific heat of product of combustion with O.	Specific heat of product of combustion with air	Number of parts of water heated 1 degree by the combustion of 1 part of the combustible.		Heating power of combustible by weight.	Heating power of combustible by volume.	Temperature of the atmosphere produced by its combustion with oxygen.		Temperature of the atmosphere produced by its combustion with air.		Heating power of the product of its combustion with air by volume.	Specific gravity of the products, calling H 1.
			Cent. Degrees.	Fahr. Degrees.			Cent. Degrees.	Fahr. Degrees.	Cent. Degrees	Fahr. Degrees		
C	·22	·255	8000	14432	22·2	57	9917	17882	2413	4375	80	15·60
C burnt to CO	·32	·286	2666	4830	7·4	19	3570	6458	1331	2427	44·43	14
CO	·22	·248	2285	4145	6·3	19	6609	11928	2580	4676	88·85	16 66
$CO + N_2$ . .	·248	·255	762	1403	2 1	6·3	2580	4676	1609	2928	53·33	15·60
H	·847	·41	36000	64832	100	21·4	4722	8531	2373	4303	100	12·33
$H_2 C_2$	·4	·305	12000	21632	33·3	100	6774	12225	2394	4341	87·5	14·37
$H_2 C$	·5	·33	15000	27032	41·6	71·4	6000	10832	2392	4337	90·9	13·81
Gas from blast furnace	·265	·267	823	1513	2 3	7	2569	4656	1589	2900	54·64	15·46

36,000°, the heating power given in the annexed table to hydrogen, is that assigned to it by Crawford. Andrews assigns 7,900° for carbon; but inasmuch as the heating power actually obtained by experiment, is more likely to be below, than above the real value, I have taken the liberty of calling it 8,000, and with the less hesitation from the fact, that the actual amount of water recently evaporated in steam boilers by 1 lb. of carbonaceous coal, leaves no doubt on my mind, that even at 8,000°, its heating powers are understated. In short, on theoretical grounds, I think it not unlikely but that the total heat resulting from its combination with 2 atoms of oxygen, is not less than 12,000°, of which about 3,000° becomes latent in effecting the gasification of the carbon, leaving 9,000° for free heating power. On this view of the case, the total calorific effect produced by its combustion, would have the same relation to that developed by hydrogen (1 to 3), as the quantities of oxygen with which they respectively combine.

Lord Dundonald, in a new and superior pattern boiler of his own construction, has evaporated 12·9lbs. of water from 100° with 1lb. of Llangennech coal, composed of 85·46 of carbon, and 4·20 of hydrogen. Assuming the carbon to have effected 85·46 per cent. of the evaporation (not an over estimate when the greater tendency of hydrogen to form smoke is considered), and we get 1lb. of carbon evaporating (in practice) 12·9lb. of water. Say water at 100° F, requires the addition of 600° C to convert it into steam of atmospheric pressure.

Then estimating the heating power of carbon at 8000° we get $8000 \div 600 = 13\frac{1}{3}$lb. of water, theoretically evaporated by 1lb. of carbon, and estimating the heating power of carbon at 9000°. $9000 \div 600 = 15$lbs. of water theoretically convertible. Now considering that in practice there is necessarily a certain amount of loss through imperfect combustion, radiation, and the current of escaping gases, I am of opinion that we can never expect to realise more than from 80 to 85 per cent. of the theoretical value. Now 12·9lbs. of water evaporated by 1lb. of carbon, is at the rate of 86 per cent. ou a duty of 15lbs. and therefore I am of opinion, that the theoretical duty of carbon cannot be less than this sum, and consequently, that its heating power should be considered 9000° instead of 8000°.

Reaumur's thermometer, divides the interval between the temperatures of melting ice and boiling water, into 80; that of Celsius, now commonly called the centigrade (the use of which is become universal in the scientific world), into 100; and that of Fahrenheit, into 180 equal parts. The first two, place the zero at the temperature of melting ice; Fahrenheit 32° below the melting point of ice. 9° F. = 5° C. = 4° R.

1° centigrade = 1·8° of Fahrenheit; but since zero, on the centigrade, commences at 32° Fahrenheit, in converting the degrees of one thermometer into those of the other, a correction must be made for its different position. If the degrees be +, to convert centigrade to Fahrenheit multiply by 1·8, and add 32 to the product.

Clement and Desormes, place the absolute zero at — 266·6 C. = —447·8 F., from the circumstance that air at zero expands or contracts) for each degree C. of heat added (or subtracted) $\frac{1}{266\cdot6}$, and therefore that at —266·6 C. there can be no further diminution of volume, and consequently no further abstraction of heat. This view must however at present be regarded as conjectural.

SECTION X.

ON THE QUANTITY OF HEAT IN STEAM AND ITS ECONOMIC APPLICATION.

191. TILL a very recent period, the total amount of heat in (saturated) steam has been always supposed to be a constant quantity, whatever its elasticity and temperature. This doctrine entailed as a corollary, the existence of a law, that the quantity of heat existing in a *combined* or latent state, varied inversely with the quantity present in a *free* state, in such a proportion that the sum of the two was always the same. Therefore it was said, that the quantity existing in a combined state increased as the pressure on the vapour diminished, and its temperature consequently fell; whilst, on the contrary, the quantity of the free or uncombined heat increased as the pressure increased, and the temperature became augmented; so that, "in a vessel whose sides would permit neither ingress or egress of heat, saturated vapour of water at 212°, might by enlargement of the space, be converted into cold (saturated) vapour of low tension, and by continual narrowing of the space, into very hot vapour of high tension, without any liquefaction taking place in the latter case (unless the space were to become too small to allow of the water existing in the gaseous state)."

192. Estimating the latent heat of steam at 100° C,=212° Fahr., as equal to 550° C,=990° Fahr., and the free heat as equal to 100° C,=180° Fahr., according to the preceding theory, we have

In vapour of	Free heat.	Latent heat.	Sum.
0°C.	0°C.	650°C.	650°C.
50	50	600	650
100	100	550	650
150	150	500	650
200	200	450	650
250	250	400	650

193. The preceding law is known as Watt's law; and is that which has always been, and continues to be, adopted by engineers, as the basis of their calculations. Southern, on the contrary, advanced the doctrine that the *latent* or *combined* heat of steam is always a constant quantity, and consequently that the *total* amount, increases or diminishes, *pari passu* with the temperature. The recent elaborate researches of Regnault have at length conclusively settled the question, and shown that neither of the two preceding theories is correct, but that the truth lies between them—Watt's theory however, involving the smallest amount of error, when practically applied to the steam engine. Watt denied there was *any* increase in the total quantity of heat in steam, as the temperature became augmented. Southern asserted that the *whole* of the augmentation in temperature, was so much heat added: Regnault has now determined that 30·5 per cent. of the augmentation, is due to an *addition* of heat—the remaining 69·5 per cent. to heat that was previously latent, becoming free (upon the diminution in the volume of the steam consequent upon the accession of pressure).

194. Regnault finds that the relation between the total quantity of heat in steam, and the temperature, may be represented within the limits of error of experiment by $\lambda = A + Bt$, and he obtains for A and B, the values $A = 606 \cdot 5$, $B = 0 \cdot 305$, so that the formula for calculating the total heat in steam at different temperatures, becomes

$$\lambda = 606 \cdot 5 + 0 \cdot 305 t.$$

In vapour at	Free heat.	Latent heat.	Sum.
0°C.	0°C.	606·5°C.	606·5°C.
50	50	571·7	621·7
100	100	537	637
150	150	502·2	652·2
200	200	467·5	667·5
250	250	430·25	682·7

195. It is not a little surprising, that a question which lies so completely at the foundation of the economic application of

steam, should have remained so long so imperfectly determined. The fact shows more forcibly than words, the chasm which has existed between the pursuits of the man of science, and the occupations of the practical man; and it may be safely affirmed, that each year since Watt's first experiment, more thousands have been wasted from imperfect knowledge, than it would have cost pounds to have set the question at rest for ever, by a series of the most elaborate experiments, conducted on the most extensive scale. The question affected the elements of national wealth, and the resources of Kingdoms—was notoriously in dispute, and equally notoriously within the reach of positive determination,—yet has this pre-eminently steam-power-using nation, allowed its solution to remain in abeyance fifty years; and it is at last to the superior enlightenment and liberality of the French government in matters of science, that mankind are indebted for its settlement.

196. One important consequence deducible from Regnault's law is, that when (saturated) steam of high temperature, and pressure, is allowed to expand, (without the presence of water) it becomes sub-saturated or super-heated steam, and as a consequence, possessed of an elasticity greater than that due to its density, in proportion to its excess of free heat; a fact which evidently most materially increases the benefit to be derived from working steam-engines expansively, and shows us that hitherto we have under-calculated the gain accruing from this process. Thus, the quantity of heat in steam of 68 lbs. pressure, and 150° C.=302° Fahr. temperature, is 27·36° Fahr. more than that in steam of 15 lbs. pressure and 100° C.=212° Fahr. temperature. Consequently, if steam of the former kind, be expanded through a space, which should according to the old law, convert it into steam of the latter, it becomes in reality sub-saturated steam, with a temperature of 244·3°, and possessing an elasticity* of nearly 18 lbs.

* Till recently, it was believed that all gases and vapours expanded equally, for equal increments of temperature, which was variously stated as

197. Another point in which Regnault's law comes in contact with the question of the economical application of steam, and, modifies in a minor degree, those data on which engineers have been accustomed to rely, is the question of the economy of high pressure steam *per se* (*i.e.* irrespective of expansion). When the temperature of water, or any other volatile substance, is raised, the *tension* of its vapour increases in a much higher ratio than its *density*, because the additional heat not only increases the tension by generating more vapour, but likewise increases the expansive force of the vapour already formed. The higher the temperature, the greater the difference, and consequently the advantage, of high pressure steam-engines, assuming the heat of steam to be a constant quantity. Now, although this assumption is erroneous, yet the increase in elasticity consequent upon an increase of temperature, much more than counterbalances the increase in the total quantity of heat, so that high pressure steam still preserves its advantages of a higher tension, in proportion to the heat required for its generation, though not to the extent that was formerly supposed.

from $\frac{1}{480}$th to $\frac{1}{490}$th of their bulk at 32°, for each degree of Fahrenheit. Muncke however long ago stated, that vapours heated to their boiling point, expand much more strongly than air; and Regnault has now established that the law, that all gases have the same co-efficient of expansion, is "true *in the limit only*; that is to say, it accords more and more nearly with the results of observation, in proportion as the gases are in a more expanded state." The expansion assumed for steam in the text, is taken from a table by Mr. Charles W. Siemens, published in the Proceedings of the Institution of Mechanical Engineers, for June, 1852. According to this table, saturated steam at 212°, when heated out of contact with water, expands under constant atmospheric pressure as follows—

Amount of expansion.			Degrees Fahr.
·1	by the addition of		7°
·2	"	"	35°
·3	"	"	75°
·4	"	"	120°
·5	"	"	165°

198. In the following table, column A shows the quantity of heat or fuel required to produce a given mechanical effect, at different temperatures and pressures, calculated according to the old view, "that the heat in steam is a constant quantity;" whilst B is column A corrected, to accord with the more precise observations of Regnault.

Increase.	Total quantity of heat.	Temperature.	Pressure in lbs.	Volume compared with vol. water that produced it.	Actual density.	Density corresponding to elasticity.	A.	B.
	1146·8	212·8	15	1669	100	100	100	100
11 8	1158.6	251·6	30	883	189	200	94·5	95·472
19·4	1166·2	276·4	45	610	273·6	300	91·2	92·742
25·2	1172	295·6	60	470	355	400	88·75	90·7
30	1176·8	311·2	75	383	435·7	500	87·14	89·419
36.4	1183·2	332	100	295	565·7	666·6	84·86	87·553
40·6	1187·4	345·8	120	251	665	800	83·125	86·067
45·9	1192·7	363·4	150	205	814	1000	81·4	84·657
53·2	1200	387·3	200	158	1056	1333	79·22	82·895

199. Much attention being excited at present to the subject of air engines, and the supposed probability of their superceding steam engines, as offering a larger return of power in proportion to the heat expended, a slight analysis of their relative powers and capabilities may prove interesting.

200. Under a pressure of 30 inches of mercury, = 14·7 lbs., 1 measure of water, yields 1,700 measures of vapour at 212° according to Guy Lussac, and 1,728 according to Dalton. We will assume the latter number, since it offers the convenient and easily-remembered ratio, of 1 cubic inch of water, forming 1 cubic foot of steam.

201. 1 cubic inch of water at 60°, weighs 252·5 grains, therefore the addition of 1,118° of heat to 252·5 grains of water at 60°, will produce 1 cubic foot of expansion under an atmospheric

pressure of 30 inches of mercury, = 14·7 lbs. raised 1,728 inches, = 144 feet.

202. 1 cubic foot of atmospheric air at 60°, barometer at 30°, weighs 536 grains; and since air at 60°, expands $\frac{1}{508}$ for each degree, the addition of 508° to 536 grains of air, will produce 1 cubic foot of expansion under an atmospheric pressure of 30 inches of mercury, = 14·7 lbs. raised 1,728 inches = 144 feet.

203. The quantity of heat required to raise 252·5 grains of water 1,118°, = the quantity required to raise 252·5 × 1,118= 282,295 grains of water 1°, (and since the specific heat of air to water is ·25 to 1), the quantity of heat required to raise 536 grains of *air* 508°, = the quantity required to heat $\frac{536}{4}$ × 508 = 68,072 grains of water 1°.

204. Then $\frac{68072 \times 100}{282295}$ = 24·11, shewing that 24 per cent. of the quantity of heat required to produce a cubic foot of expansion, (under atmospheric pressure, with the barometer at 30° and the thermometer at 60°), by the conversion of water into steam, will produce this effect when applied to expand air.

205. So far, the balance of advantage would appear to lie on the side of heated air, in the proportion of 4 to 1, when compared with steam as a moving power; but there remain two most important considerations to be examined, which not only turn the balance the other way, but to such an extent, as in my opinion to render it in the highest degree improbable, that heated air can ever become an advantageous substitute for steam, as a prime mover.

206. The first great drawback to the use of heated air, is the small amount of its expansion. Water, we have seen, expands 1,728 times; so that to obtain a volume of expansion of 1 cubic foot, we have only to force into the reservoir where the expansion is effected, (*i.e.* the boiler) a volume of 1 cubic inch. Now, could we obtain air in any similarly condensed and manageable form, yet, retaining its present small capacity for heat, it would stand on a totally different footing, from that which it actually

occupies. Even at 569° however (which is probably above the temperature at which it could be practically used with advantage in a cylinder with air-tight piston), its volume (at 60°) is only doubled; consequently, for every volume of heated and expanded air which develops power as it escapes by the *working* cylinder, half a volume of cold air must be forced into the reservoir where the heating and expansion are accomplished, by the *supply* cylinder, —an operation which at once consumes half the theoretic power of the engine, plus the friction of the supply cylinder with its valves and appendages, and increases its consumption of heat for duty done, to considerably more than double—say from 24 to 60 per cent., as compared with the steam engine.

207. The second great disadvantage under which an air engine labours, may be said to be included in the first. It is this,—that the small degree of tension it is possible to employ, from the limit placed by the question of temperature, not only virtually precludes the employment of the principle of working expansively to any extent, but also entails the necessity of employing cylinders of an enormous and unwieldy size, in proportion to the power obtained. By cutting off the steam when the piston has made $\frac{1}{8}$th of the stroke, its duty may be increased more than three-fold, reducing the consumption of fuel to 33 per cent. Now, even supposing (what I believe to be practically impossible) that working expansively might be carried sufficiently far in the air engine, to reduce its consumption of fuel from 60 to 33 per cent.—thus placing it on a level with the steam engine, with regard to consumption of fuel,—in proportion to the amount of pressure obtained on the piston; the steam engine would still possess an immense preponderance over its antagonist in practical utility and convenience, on account of the huge bulk of the latter,—an air engine requiring its working cylinder to be from 10- to 50-fold the area of that of a steam engine, together with a second cylinder, as supply cylinder, about two-thirds the size of the first.

208. This is stated to be the proportion between the

cylinders in the marine air engine of Captain Ericsson's, which now excites so much attention, whilst the tension obtained is said to be 9 lbs. Since two-thirds of this, exclusive of friction, will be absorbed in working the supply cylinders, we can scarcely calculate the effective pressure at more than 1½lb., necessitating the use of cylinders of Brobdingnagian dimensions; and notwithstanding the new and important principle Captain Ericsson has called to his aid, in his highly ingenious *caloric regenerators*, the steam engine possesses at least an equivalent in the condenser; and I feel satisfied that if tested, this engine would have to yield the palm for duty performed, compared with fuel consumed, to our best Cornish engines.

209. In short, there is not at present on the horizon the faintest dawn of the appearance of any mode of generating force, calculated to compete with, much less to supersede, the steam engine. Whether a time may ever arrive when we may be able to concentrate, and economically employ, the immense currents of thermo-electricity which we know must result from the action of the sun's rays and the rotation of the earth, and thus obtain a supply of power as costless as a running stream, the wind, or the tides; yet without the intermittent character which interferes with the practical application of the two latter, is a question at present purely problematical, and no earnest of future success has yet been obtained. Electro-magnetism, from which once (from imperfect knowledge) much was expected, is now thoroughly understood to be a far more costly mode of obtaining power, than the combustion of coal. Heat, electricity, magnetism, chemical affinity, force, are all equivalent to each other, according to ratios which are fixed and unalterable. The atomic weight of carbon is 6, that of zinc 32: 1 lb. of carbon will develop more heat, and consequently more force, than 5 lbs. of zinc; whilst, weight for weight, the cost of the former is to the latter as 1 to 50. On this subject Liebig aptly observes, "it is highly probable, that if we were to burn under the boiler of a steam engine, the quantity of coal required for smelting the zinc from its ores, we should produce far more force, than the whole

of the zinc so obtained could originate, in any form of apparatus whatever."

210. The practical inference to be drawn from the preceding considerations is,—that the improvement of the steam engine—the means of obtaining from it a greater return of duty, in proportion to the fuel expended—is one of the most important subjects which can engage the attention, and occupy the energies, of a manufacturing and commercial people.

211. That great advances can, and will be made on our present achievements, none can doubt, who have examined and compared for themselves, its theoretical capabilities, with its present performances. The direction in which an increase of duty is to be sought, is, in my opinion,—1st, by using steam of a higher pressure; 2ndly, by applying heat directly to the cylinder and steam pipe. Both of these expedients have an economic value *per se*, and both contribute to increase the advantages of working expansively, not only by imparting to this system a higher value within a given range, but also by increasing the range to which it may be beneficially extended, by lessening the disparity between the initial, and terminal pressures of the steam.

212. If we use steam of 90 lbs. pressure, and cut off at $\frac{1}{8}$th., and by the application of heat, keep the cylinder at a temperature which will ensure its not abstracting any heat from the steam, then, at the termination of the stroke, instead of atmospheric steam of 15 lbs. pressure, we shall have atmospheric steam + 34°, or, in other words, sub-saturated steam of 18 lbs. pressure. Now, 18 lbs. is only $\frac{1}{5}$th of 90 lbs., so that in reality, we realize the effect of cutting off at $\frac{1}{5}$th, not only with respect to the amount of disparity between the initial and terminal pressures, but also as regards the sum of the duty done. If, on the contrary, (using the same pressure and degree of expansion,) a portion of the steam be allowed to undergo condensation in the cylinder, the result is, that at the termination of the stroke, the pressure becomes reduced to 13 lbs., or even less, diminishing in

reality the performance of the engine below that assigned by theory to cutting off at $\frac{1}{7}$th. In short, to equal the pressure on the piston obtained by cutting off at $\frac{1}{6}$th, where the application of heat to the cylinder prevents the abstraction of any from the steam, (equalling a terminal pressure of 18lbs.), in an engine where this precaution is neglected, it would be necessary to cut off at about $\frac{1}{4}$th. Now, the difference in the consumption of steam or fuel, between cutting off at $\frac{1}{4}$th or $\frac{1}{6}$th, amounts to 33·3 per cent, and I believe this to be by no means an exaggerated representation, of the relative economy of the two systems.

213. In short, whenever engines are worked expansively, (and all are, or should be), and more particularly condensing engines, heating the cylinder should be deemed a *sine quâ non*, and to neglect doing so, an act of consummate folly, inasmuch as it is a wanton sacrifice of 30 per cent. of useful effect, when no obstacle exists in the way of its attainment. What makes such remissness the more unpardonable, is the fact, that the advantages of the system have been practically demonstrated and proclaimed in Cornwall for twenty years past; whilst the explanation of its mode of action, was made clear by the publication in this country, in 1848, of the researches of Regnault. Extraordinary however as such a statement may seem to the reader, I believe it to be a fact, that there is not at the present moment, either in the Royal Navy, or the mercantile marine, a single steamer fitted with any apparatus for heating the cylinders, and as a necessary consequence, all their attempts to carry the principle of working expansively, beyond the narrowest limits, prove abortions.* The cause of this singular supineness must be

* At a recent trial of one of Her Majesty's screw steamers, constructed with four cylinders, for the express purpose of better obtaining the economy due to a considerable extent of expansive working, it was found that a better effect was obtained by using only two cylinders, and cutting off at half stroke, than by using the same quantity of steam in the four cylinders, and cutting off at one-fourth, although theoretically, the result in the latter case ought to have been nearly 50 per cent. more. The cause of the anomaly was obviously the greater proportional condensation of the steam by the four cylinders, than by the two, and the result might have been predicted.

sought in the fact, that the manufacture of steam engines is regarded too much from a commercial point of view, by those engaged in it; whilst the want of knowledge of the subject in those who order, and pay for them, places them entirely in the hands of the makers.

214. The following calculation of the theoretic capabilities of the steam engine, is interesting and instructive, and likely to be of utility, by begetting that *faith* in the success of efforts for its improvement, which is the parent of earnest endeavour.

215. I shall first estimate the theoretic power of an engine worked with an initial pressure of 150 lbs., cutting off the steam at $\frac{1}{10}$th of the stroke. Next, of an engine worked with an initial pressure of 90 lbs. cutting off at $\frac{1}{6}$th* of the stroke. In both

* I believe the time will come, when it will be quite an exceptional case, for an engine to be worked at a lower pressure, or at a lower grade of expansion than this, for the simple reason, that there is nothing to prevent this degree being generally used, and therefore, that to employ less, will be regarded as sacrificing economy without an object. The ignorance which prevails on this subject at present is quite extraordinary. Thus, in the Jury's report of Class V. of the Great Exhibition of 1851, we are told, with reference to a French steam engine otherwise commended, "The high pressure (75 lbs. per square inch) at which it is proposed to work this engine, is however to be deprecated, as attended with great risk, and *with great loss, by reason of the high temperature.*" It is to be regretted that a reporter on the subject of steam engines, should have been unacquainted with the fact, that the Cornish engines, which greatly surpass all others in economy, habitually use steam of 75 lbs. pressure, and often above; whilst, with regard to the frequency of explosions, they present a marked and happy contrast, to what appears to be the rule in other parts of the kingdom. In treating of rotary engines, the same report informs us, that "thanks to the more general diffusion of information in mechanics, practical men now know, that there is no more possibility of increasing the work of an engine, by merely altering the direction of the motion of any of its working parts, than there is of increasing the quantity of water which a reservoir will supply, by varying the pipes which serve to distribute it." Thus we are required to believe, on high authority, that there is no loss of momentum (=power) from the arrest and reversal of motion, inseparable from all reciprocating engines. Fortunately, the simple instincts of most men will suffice to prevent their being indoctrinated with such an absurdity.

cases the internal surface of the cylinder to be preserved at the temperature due to the initial pressure of the steam, so that at the termination of the stroke, no heat shall have been abstracted from the steam by the cylinder, but on the contrary, a slight amount added. The theoretic values thus obtained, I shall then compare with the actual performances of our present Cornish and marine engines.

		lbs.
Steam of 150 lbs., cut off at $\frac{1}{10}$th., will exert a mean pressure of		49·5
Allow 10 per cent. for increase in elasticity, from steam becoming sub-saturated, with 46° surplus heat, and a tension of 18·5 lbs. at the end of the stroke	=	4·95
Vacuum		12
Total . . .		66·45

lbs. lbs.
66·45 × 144 = 9568·8 raised 1 foot, by 1 cubic foot of atmospheric steam + 46° of heat.

lbs. vol, of steam,
568·8 × 1669 = 15,970,327 raised 1 foot, by the conversion of 1 cubic foot of water, into steam of 150 lbs. = the addition to 1 cubic foot of water at 100°, of 1078·8° + 46° of heat.

		lbs.
Steam of 90 lbs., cut off at $\frac{1}{8}$th., will exert a mean pressure of		42
Allow 10 per cent. for increased elasticity, from steam becoming sub-saturated, with 34° surplus heat, and a tension of 18 lbs. at end of stroke	=	4·2
Vacuum		12
Total . . .		58·2

lbs. lbs.
58·2 × 144 = 8380·8 raised 1 foot, by 1 cubic foot of atmospheric steam + 34° of heat.

lbs. vol. lbs.
8380·8 × 1669 = 13,987,552 raised 1 foot, by the conversion of 1 cubic foot of water, into steam of 90 lbs. = the addition to 1 cubic foot of water at 100°, of 1078·8° + 34° of heat.

A cubic foot of water weighs 62·32 lbs. Allowing 5 lbs. of coal to evaporate this quantity, (= 12·464 lbs. per lb. of coal, and 12·9 has been done) we get as the theoretical duty of 1 lb. of coal—

	lbs.		lbs. coal.		Per centage of duty.
In engine with initial pressure of 150 lbs., and cutting off at $\frac{1}{10}$th	3,194,065*	raised 1 ft.	= ·62	{ per h. p. per hour }	100
In engine with initial pressure of 90 lbs., and cutting off at $\frac{1}{8}$th	2,797,511	"	= ·70	"	87·58
Utmost duty known to have been performed by a Cornish engine . . .	1,329,787	"	= 1·48	"	41·63
Common amount of duty for a superior Cornish engine .	1,000,000	"	= 1·98	"	31·30
Average duty of Cornish engines .	750,000	"	= 2·64	"	23·48
Average duty of best marine engines .	450,000	"	= 4·4	"	14·09

216. The chief obstacle to our using high-pressure steam, is the belief that safety would be compromised by so doing. Now I frankly admit, that if the use of high-pressure steam will entail as a necessary consequence, a more hazardous state of things than exists at present (when one can scarcely take up a newspaper which does not contain the details of some shocking catastrophe, attended with the loss of life from the bursting of boilers†),

* Equals 227 lbs. raised 1 foot, by heat sufficient to raise 1 lb. of water 1° Fahr. Mr. Joule estimates the mechanical value of this quantity of heat applied to air, to be equal to raise 782 lbs. 1 foot. But, in capability of practical application, air is, as I have already explained (see par. 206), greatly inferior to steam.

† This subject ought to be made an object of legislation, not by vexatious enactments intermeddling with the structure of boilers, or the pressure of steam, but simply by requiring every boiler to be periodically tested to three times its working pressure, and a certificate of the fact attested by signatures, forwarded to the proper officer. The *laissez faire* system has already been tried too long in this matter, one in which human life is at stake, and where the unfortunate victims, principally made up of the workmen in factories, have no power to protect themselves. Public safety, in cases where the public have not the power of self-protection, is unquestionably a proper object for a

all idea of extending its use should be definitively abandoned. It is however easy to show, that nothing of the kind is to be anticipated, and that however plausible in appearance, may be the popular notion, which connects danger with high-pressure steam, it is in reality a prejudice which will not stand the test of examination.

217. As we boast of being a practical people, let us first test the question by practical results, and appeal to facts. The engines which use the highest pressure steam (amounting sometimes to 120 lbs.) in this country, are the locomotives; yet it is not from this class that the sad list of casualties by explosions is made up, and the Cornish engines, which come next with regard to pressure of steam, enjoy a like immunity from disaster. The same smaller per centage of accident attending the use of high-pressure boilers which prevails in this country, extends likewise to America, it having been stated in a memorial to Congress, that since the more general introduction of high-pressure steam, the number of accidents had not only not increased, but had become lessened in an extraordinary degree.

218. That such would be the case, is precisely what a knowledge of the subject would lead us to anticipate. Dr. Ernst Alban justly observes, "As the strength of the metal is adapted to the working pressure, the proper elasticity for which the vessel is constructed, must be exceeded before an explosion can occur; but there is an advantage on the side of the high pressure engine, for the elasticity must be increased in a much higher ratio, than with the low pressure engine, before it overcomes the pressure at which the boiler is proved (usually three times the working

legislative enactment. A subject that calls aloud for it at the present moment, is that of the adulteration of food. Now that in addition to chemical tests, the microscope has placed such an unerring and easily available detective officer at our command, this gigantic system of fraud and imposture, might easily be strangled, with no injury to any but the miscreants who gain a dishonest livelihood, by ruining the honest trader, and slowly poisoning the rest of the community; and compared with whose doings, the occupations of ordinary criminals are harmless.

tension); and therefore a much longer time will elapse, before absolute danger arises. For example, in a boiler working at 8 atmospheres, it will take a much greater lapse of time for the pressure to rise to 24 atmospheres, than it would to reach 24lbs. per square inch in a boiler working at 8lbs.; and these would be the points at which danger may be supposed to arise in the respective cases." M. Arago notices the same fact, and characterizes the fear of high-pressure boilers as mere prejudice. See *Echo du Monde Savant*, No. 484.

219. The great point we have to look to however, to ensure perfect freedom from all danger of explosion, both with high-pressure and low-pressure boilers, is the substitution of boilers consisting wholely of tubes of moderate dimensions, in place of the *huge* (and therefore dangerous) chest or barrel-shaped vessels in use at the present day; and also the substitution of copper for iron, more particularly for marine boilers. Since the strain on the boiler plate is, *ceteris paribus*, directly proportionate to the diameter of the vessel, the same thickness of boiler plate which would be selected for a marine boiler 12 feet square, to work at a pressure of 15lbs., and consequently as competent to undergo a test of 45lbs., would, if made into a tube of 12 inches diameter, be competent to undergo a strain of 540lbs.; and would, if used in this form as a boiler for high-pressure steam of 150lbs., be so infinitely safer than with steam of 15lbs. pressure, and the former dimensions, that any attempt to put the two in competition would be ridiculous, since in one case we have a boiler working at 30lbs. below the strain to which it might safely be subjected, in the other at 390lbs.

220. Iron is an unsuitable material for marine boilers, from the facility with which it becomes corroded; and whilst its use is continued, in conjunction with the present form of marine boiler, that degree of assurance against liability to danger, with less than which we ought not to be content, can never be permanently maintained. Copper, though the first cost is five times that of iron, lasts five times as long, and is worth half-price when worn

out; whilst its conducting power being as compared with iron, as 2·4 to 1, a much smaller extent of heating surface, and water space, suffice. Its crowning advantage however is its safety, from the circumstance that it does not fly asunder, causing destructive explosions, like iron, but from its greater ductility, simply opens with a rent, which seldom causes any serious damage. Indeed, by leading a pipe into the funnel weaker than the rest of the boiler, so as to insure this part being the first to give way in the event of undue pressure taking place, even the risk of scalding is prevented, and no more danger need ensue from the rupture of a boiler, than from the opening of a safety valve.

221. We may then assure ourselves of this, that if high-pressure steam is more economical than low, we need not debar ourselves from its advantages, by any apprehensions on the score of safety. It would indeed be an extraordinary thing, if, whilst Faraday in his experiments on the liquefaction of the gases, can obtain a pressure of 50 atmospheres in glass tubes, any real difficulty or danger should exist, in subjecting copper ones, to a pressure of 10.

222. Watt, who filled a large sphere of activity during his useful career, found at its commencement, the art of construction in metal in so rude a state, that as a preliminary to making an efficient steam engine, he had to construct machines for the manufacture of its several parts, and educate workmen to use them. The imperfect workmanship of his day, threw an obstacle in the way of the application of steam of very high-pressure, from the difficulty of obtaining valves sufficiently steam-tight. Were Watt to reappear at the present day, with its greatly improved facilities for workmanship at his command, he would be the last man to rest apathetically contented with his former achievements. On the contrary, it is not to be doubted, but that he would apply himself assiduously and successfully, to realize the increase of duty, theory shows to be placed within our reach, by the judicious application of high-pressure steam. The present is not as the past. The foreigner treads on our heels.

We live in an era of progress, in which those who do not advance are left behind. In no other country is theory and practice so disjoined as in England, where men follow by routine, professions, without any knowledge of those scientific principles, upon which all their proceedings should be based. From year to year do they contentedly travel on in one jog-trot pace, with all the contempt for novelty, which it is the province of ignorance to engender, and that overweening self-confidence and conceit, which arises from limited vision. The day arrives when this misplaced self-satisfaction is rudely overthrown by defeat, and nothing then equals their surprise and astonishment,* but their previous blindness and obstinacy.

* Witness the *effect* produced by the well-earned triumph of the yacht *America*. Five years before, some of our leading yacht's-men and most celebrated yacht builders had their attention called to the subject of hollow bows, with a hint that if they continued to refuse to adopt them, the result would be, that sooner or later their crack craft would get disgracefully beaten. The friendly warning was received with contempt and derision. One well-known builder wrote a work on ship building, containing the usual orthodox platitudes on—*new fangled notions,—presumption of those who set aside the authority of ages,—folly of abandoning rules sanctioned by experience, &c. &c.* The same year which witnessed the publication of this book, witnessed the victory of the *America*, furnishing an appropriate commentary on the wisdom of the writer.

We are now (1853) busily engaged in building Screw line-of-battle ships, but instead of being in our proper position—the *leaders* of the world—we are become *followers*, in the wake of the Americans and the French. In 1837, Capt. Ericsson (who subsequently introduced the Screw in the United States) with a small Screw vessel only 45 ft. long and 8 ft. wide, towed the Admiralty barge, with their Lordships on board, from Somerset House to Blackwall Wharf, at the rate of 10 miles an hour. Notwithstanding the highly satisfactory result of the experiment, Capt. Ericsson was told, in a reply which the subsequent success of the Screw has already rendered historical, "*that their Lordships declined to entertain the project.*" One would have supposed that the vast superiority of the Screw over the Paddle-wheel, for vessels of war, would have been seized at a glance, but some are afflicted with weak vision; and as Schiller so forcibly and happily expresses it "Mit der Dummheit kämpfen Götter selbst vergebens." "Alas! there is no possibility for poor Columbus at any of the Public Offices, till once he become an Actuality, and say "Here IS the America I was telling you of."—*Carlyle's Life of Cromwell.*

An examination of the question whether heat be a material substance, or simply the result of vibrations of the atoms of bodies, as supposed by Davy, would be inconsistent with the objects of an elementary work like the present. Those who are desirous of investigating the subject, will find an interesting paper advocating a theory of vortices, by Mr. Rankine, in the Transactions of the Royal Society of Edinburgh, vol. xx. part 1. entitled "On the Dynamical Theory of Heat."

The fundamental suppositions are: *First, that each atom of matter consists of a nucleus or central physical point enveloped in an elastic atmosphere, which is retained in its position by forces attractive towards the nucleus or centre.*

The *second supposition*, being that from which the hypothesis of molecular vortices derives its name, is the following: *that the elasticity due to heat arises from the centrifugal force of revolutions, or oscillations among the particles of the atomic atmospheres; so that quantity of heat is the* vis viva *of those revolutions or oscillations.* This supposition appears to have been first definitively stated by Davy.

To connect this hypothesis with the undulatory theory of radiation, Mr. Rankine introduces a *third supposition: that the medium which transmits light and radiant heat, consists of the* nuclei *of the atoms vibrating independently, or almost independently of their atmospheres;* so that the absorption of light and of radiant heat, is the transference of motion from the nuclei to their atmospheres, and the emission of light and of radiant heat, the transference of motion from the atmospheres to their nuclei.

APPENDIX.

ON DWELLING-HOUSE GRATES AND VENTILATION.

Of all the discoveries of the present age, none is likely to be more prolific in benefit, than the recognition of the great truth, that the physical well-being of a people, is a necessary preliminary to their moral progression. As the blossoms of the plant unfold themselves under the influence of genial sunshine, but are nipped, and repressed by the chilling wind of winter, so do what may aptly be called the blossoms of man's mixed nature, his social, kindly, benevolent, and imaginative tendencies, and his reverence for the true and beautiful, expand themselves, and reach their highest stage of development, when unimpeded in their growth by the irritable and selfish feelings which unsatisfied physical wants are prone to call into action. The inventor of the steam engine, did more to promote the progression of his species, in morality, virtue, and happiness, than any twelve of the most eloquent preachers that ever addressed an assembly; because, in proportion to the ease with which men can furnish themselves with the necessaries of life, will they be lifted above an exclusive preoccupation with their animal and selfish instincts, and acquire leisure for the cultivation of the nobler portion of their nature.

The most effectual way to improve mankind, is to make the path to improvement easy, for it is precisely those who are the deepest sunk in degradation, and have the greatest need of amendment, who are the least amenable to the influence of precept and teaching. If, for instance, the metropolis and all our large towns, were to be copiously and cheaply furnished with a supply of pure water; and were there erected, at suitable intervals in every thoroughfare, a marble stand and fountain, tended by some cleanly matron in fresh starched cap and snow-white apron, whose duty it should be to furnish to every passer-by who requested it, a glass of nature's greatest luxury "without money and without price," intemperance would receive a death blow, which all the laudable efforts of temperance societies, have hitherto failed to inflict upon it. What a noble object for the ambition of a statesman to have his name associated with such an undertaking, a measure which would elevate his character in the eyes of his countrymen, more than a hundred triumphs in party squabbles, and constitute him the benefactor of generations yet unborn. But alas! our rulers of the present day, with all the advantages of modern civilization, seem to have a more imperfect knowledge of what true greatness really consists in, as well as of their duties to the people they govern, than the old Roman, Appius Claudius.

More indispensable however than even a pure supply of water, is that of fresh air, and the subject of ventilation is so closely connected with that of heating, that it is difficult to consider them apart. Fifteen times per minute does man inhale the breath of life, and discharge it from his lungs shorn of one-fourth part of its oxygen—with the quantity of carbonic acid increased more than 100-fold—and impregnated in addition, with noxious animal impurities. The air issuing from the ventilator of a crowded apartment, is of so deleterious and poisonous a nature, that it is dangerous to breathe it even for a short space of time; and pure water through which it has passed becomes putrid. In the close, overcrowded, and ill ventilated habitations of the poor, it is this same noxious animal emanation in the breath, combined with that of the perspiration, which, becoming condensed upon the walls and furniture, imparts to such apartments their peculiar sickly, noisome, and fœtid odour, giving origin to fevers, and producing a lowering of the tone of all the vital functions, predisposing the occupants to the attacks of disease in general.

If this description is inapplicable to the dwellings of other classes of society, it is more from the larger size of their rooms, and their greater care in cleansing them, than from the adoption of any systematic and adequate plan of ventilation. Unfortunately, the *association* of this, with their idea of cleanliness, is yet to be effected, and we daily see persons scrupulously clean in their persons, most unsparing in the ablutions of their bodies and apartments, perfectly indifferent on the subject of aerial contamination, and apparently ignorant of its existence. There are however many gradations of defective ventilation, and if the dwellings of the middle and upper classes, do not offend our olfactory organs on entrance, from the stale accumulations of putrid effluvia, they are nevertheless devoid of that freshness and sweetness, which only free and ample ventilation can impart, and the health of the inmates is wanting in the vigour, robustness, and elasticity, characteristic of a perfectly normal state.

When crowded evening parties, with their adjuncts of gaslights and candles, take place in apartments where no arrangements for ventilation are provided, an atmosphere is produced perfectly intolerable to those whose feelings have not been blunted by habit. When it is considered that an individual respires about one-sixth of a cubic foot of air per minute, and that this, by mixing, renders 2 or 3 cubic feet unfit for respiration, so that in order to preserve a pure atmosphere in a room, the lowest estimate of supply required, is 4 cubic feet per minute for each individual, we shall be painfully impressed with the ignorance of those hosts, who crowd their apartments with guests, for whose entertainment they spare no luxury which wealth can supply, whilst they make no provision for furnishing them with that most indispensable of all requisites to life and vivacity—*pure air*, but poison them with noxious aerial contaminations, and send them to their homes, dull, listless, depressed, and irritable.

The habit of excluding fresh air, is unquestionably greatly fostered by the craving for warmth, and the deficient power of our heating appliances to keep up the degree of warmth most congenial to our feelings, when a free circulation of fresh air is allowed. To the poor, fuel is a very expensive item, so that we can hardly wonder at their attempting to economize it at the expense of ventilation, of the necessity of which they are ignorant; and all endeavours to induce them to change their system will I feel assured prove fruitless, till we enable them to do it without sacrificing that warmth they so much enjoy, and which defective food and clothing too frequently disable them from dispensing with. It is under this point of view, that the improvements of their grates becomes so important, for could we put them in possession of a means of producing twice or thrice the amount of heat, with the same expenditure of fuel, I feel assured an improved ventilation of their apartments would follow as a necessary consequence, whilst without it, our utmost efforts in this direction will have but a very limited effect.

Till within a comparatively recent period, in no department has a more singular want of intellect been conspicuous, than in the prevailing form of dwelling-house grates, which might have been supposed to have been constructed with a view to distilling and dissipating a certain quantity of fuel, and sending the products up the *chimney*, and with an opening into the *apartment*, merely for the purpose of inspecting the process, and renewing the fuel, rather than to have been fabricated for the express object of *heating* the latter. A square box for the fuel, standing in a deep recess, with straight jambs running parallel to its sides, so as to reflect as little as possible of the heat into the apartment, with a wide yawning chimney placed directly above the fire, formed an *ensemble*, the object of which it surely would have been pardonable to mistake.

Nothing more clearly shows the force of habit, and how few persons possess an intuitive perception of the tendency of such arrangements, and their consequent absurdity, than the fact, that such a system of construction should have so long maintained its ground, particularly when it is considered that the principles which should govern the construction of a fire-place, are few, simple, and obvious.

It is true that many *very* improved forms of grates have been recently introduced, many very excellent in *certain* points, but none such as I have long desired to see, viz. a model possessing every feature of excellence in the highest degree in which such a combination is attainable. The test of a grate should be a thermometer, and its artistic merits, as far as beauty of form, material, and workmanship go, should be made a separate question, and not mixed up with the consideration of its heating capacities. Let perfection, or its nearest attainable approximation in the latter qualification, be once realized, and beauty of form, and appropriateness of decoration, may easily be superadded by some other hand, requiring as they do, faculties of an essentially different class, in the designer.

The present remarks have been written with the intention of taking a precise view of the objects most desirable of attainment, for the purpose of deducing some general fixed principles of construction, the correctness of which, becoming universally recognised as indisputable, a more uniform degree of excellence in the manufacture may be hoped for; whilst the public being educated to a knowledge of the subject, will reject inferior productions, even though set off with a high degree of artistic skill and beauty.

The first position I shall lay down, is, that it is desirable to obtain the greatest possible quantity of heat from the fuel, 1st, by direct radiation, 2ndly, by reflection, and 3rdly, by secondary radiation, before it passes into the region of the flues. This position would of course be a mere truism, if made with reference to a fire-place which possessed no contrivance for extracting a portion of heat from the current of hot air proceeding from the fire, before its final dismissal by the chimney into the atmosphere. What I am desirous of stating however is, that whatever contrivance is resorted to for this object, whether hot air flues, hot water pipes, or a circulation of air over a hot surface, it is nevertheless desirable, *previously*, to obtain all the heat by direct radiation, reflection, and secondary radiation, (the two former more especially,) which we can succeed in eliciting, because such heat is *superior in quality*, more *rivifying, envigorating, genial, and grateful* to the feelings of man, and animals, than that furnished by heated currents of air, technically termed convection.

Should any one demur to this proposition, and argue that heat is heat, and that chemistry is cognizant of only one kind of caloric, my reply is, that whilst our knowledge of a subject is confessedly so imperfect, as is the case with regard to heat, the universal instincts of man and animals, should be held to be a much safer guide, than any scientific theories framed in opposition to them. Only those who have a *most superficial* acquaintance with science, can fall into the error of supposing that all her present deductions are perfect and infallible, and to act as if such were the case, and obstinately to reject opinions fortified by the general consent of mankind, merely because they cannot be brought to square with the prevalent scientific hypotheses of the day, is indicative of a shallow and short-sighted understanding. It is this unauthorised, and too often supercilious rejection by smatterers in science, of the conclusions arrived at by a long course of experience and observation, which more than anything else contributes to produce, and goes far to excuse, that contempt for scientific considerations, which is the besetting weakness of practical men, and which becomes the unfortunate means of severing two classes, who can do much to assist each other.

Arguments however are certainly superfluous to convince an Englishman, of the superiority of an open fire, over any system of warming by close stoves, or heated currents of air. Even the ingeniously arranged stove of Dr. Arnott, backed by his deservedly high authority, and the powerful consideration of economy, failed to persuade his countrymen to forego that cheerful adjunct to their dwellings, in whose rays they love to bask. And there is no doubt that their instinctive feelings serve them faithfully, and are much safer guides to be followed, than any abstract considerations founded on scientific theories of the unity of caloric. Let a man return home tired and fatigued, after a day's exposure to wet and cold, can any one even *imagine* that under such circumstances, the heat of a close stove would be found as grateful and sufficing to his feelings, as cheerful, enlivening, and restorative, as that of an open fire? unquestionably not; and since such marked difference in effect, must have a cause, we are as well warranted in assuming a difference in the quality of the emanations which impinge on our nerves, as if we could exhibit this difference under a microscope, or weigh it in a balance. Very contracted must be the ideas of those who cannot imagine the possibility of the existence of agencies in nature, the effects of which cannot be exhibited in any change in inorganic matter, but which find their proper sphere of action in the organic world.

Our knowledge of the emanations from fire, is besides far too limited, to warrant any dogmatic assertions of their not being of a compound nature, indeed there are many facts which go to prove a variation in the properties of heat, according to its source; and even if, as may very plausibly be argued, this variation depends merely in difference of velocity, this by no means impairs the validity of our argument, that there are different qualities of heat, independent of mere thermometric intensity, as far as its power of acting on the organism of animated beings is concerned.*

* Some of the facts however, brought to light by the most recent researches on heat, are with difficulty explainable on the theory that its properties vary only as the result of variations in velocity, but seem to point to the existence of differences of a more specific nature. Thus, although as a *general* law, the hotter the source of heat, the greater the number of the more refrangible rays emitted from it, and the lower the temperature, the greater the number of the less refrangible, the law is only absolutely correct, with regard to each source, compared with itself, at different stages. "Every source sends forth however a mixture of calorific rays of the most various degrees of refrangibility, the proportion only, varying with the nature of the source. For these different rays of heat, bodies exhibit different absorbing powers. Snow, whose whiteness shews that it reflects the various refrangible rays of *light* in equal proportion, absorbs chiefly, the less refrangible rays of *heat*, and reflects the more refrangible. Hence it does not melt so quickly in direct sunshine, as in the neighbourhood of stems of trees and other solid

It must not be supposed, that in advocating the propriety of obtaining the largest possible amount of heat—by direct radiation from the ignited fuel,—by reflection,—and lastly, by secondary radiation, before the heat is allowed to escape into the regions of the flues, that I propose to neglect the means of still further economy open to us, by extracting a portion of the heat contained in the products of combustion, instead of allowing it to be wasted and pass unused up the chimney. On the contrary, so wasteful and extravagant a system ought never to be deemed satisfactory; and where large and long rooms are to be heated by a single fireplace, without some plan is adopted for transfering the heat to the portions most distant from the fire, either by hot water pipes, hot air flues, or heating the current of air with which the apartment is supplied, a satisfactory equalization of the temperature in all parts of the room is scarcely to be attained. What I contend for is, that since the extraction of the greatest possible amount of heat, by direct radiation from the burning fuel, by reflection, and by secondary radiation, as a *first* step, in no way interferes with the *after* treatment of the products of combustion, in any method which shall be deemed

bodies, which, when warmed by the sun's rays, emit calorific rays of less refrangibility; not so quickly, when freely exposed to an Argand lamp, as under a covering of black paper which does not touch the snow; not so quickly by the rays of an Argand lamp, as by those from a piece of metal heated to 720°, when both are placed at such a distance, that their heating powers are equal." (*Melloni.*) This seems to shew that the more refrangible rays of heat, when they are absorbed by bodies, and afterwards emitted from them, are converted into rays of less refrangibility. Lamp black, on the other hand, appears chiefly to absorb the more refrangible rays. "Common salt transmits all rays of heat equally well; most diathermanous bodies chiefly transmit the more refrangible, and absorb the less refrangible rays. Common salt covered with lamp black, is the only substance chiefly pervious to the less refrangible rays." "When the light of the sun is made to pass through water, which absorbs the less refrangible rays of heat, then through glass covered with oxide of copper, which takes up the more refrangible, it is totally deprived of its heating power." (*Melloni.*) "The maximum of heat is found in different parts of the spectrum, according to the nature of the prism." (*Seebeck.*) "The quantity of radiant heat transmitted through diathermanous bodies is not directly proportioned to the temperature of the source, but depends only on the constitution of the diathermanous body, each body being permeated by certain calorific rays, more readily than by others, whether those rays are emitted at a higher, or at a lower temperature. The heating effect produced, when the radiated heat which reaches the bodies is of given intensity, is totally independent of the temperature of the source, and determined only by the nature of the absorbing bodies, which receive certain rays more readily than others." (*Knoblauch.*)

most desirable, for making them yield up a portion of the heat with which they are charged, and since moreover we have seen that the heat attainable from the first-named sources is of a superior quality to that derivable from the second, its attainment in the largest possible quantity, should be the *first object aimed at.*

It is commonly supposed that the disagreeable sensations experienced by breathing the atmosphere of apartments heated by closed stoves, depends upon—the temperature of the iron casing being sufficiently high to burn the particles of dust and other impurities floating in the air, together with—the dryness of the atmosphere produced. That the latter cause, viz. the great change effected in the hygrometric properties of the air, by the disproportion between its temperature and its dew point, exercises a considerable influence on the animal economy, when long subjected to its operations, there can be no doubt, but that it is the sole, or even principal cause of the effects experienced from the use of stoves, is, I think, more than questionable. If I mistake not, influences of a more subtle nature are at work, and it is far from improbable, but that these may consist of changes in the electric or magnetic qualities of the air, induced by contact with the heated metal. As far as my own sensations go, I always experience a certain sense of *malaise* when in an apartment heated by an iron surface, although such surface is at a comparatively low temperature, as in the case of an Arnott stove, or hot water pipes, and notwithstanding a hot water vessel may be employed to afford due moisture by evaporation. Even the atmosphere of the spacious and lofty hall at the Euston Square Terminus, (which is heated by hot water pipes) is to me excessively disagreeable, and if long breathed, would be productive of headache, and other unpleasant effects, which I have not experienced from the Continental stoves, covered, both stove and pipe, with porcelain.

Ventilation has lately been considered divisible into two systems, the methods of *plenum* and *vacuum*; by the first, air is *forced* into the building by some mechanical contrivance, and allowed to escape through apertures left for this object; by the second, the building is either ventilated by the ascending force imparted to the air by its increased temperature when discharged from the lungs, or its exit is facilitated by the aperture left for ventilation in the upper part of the room, being led into the chimney, or some shaft connected either with a furnace, or a fan in the upper part of the building, whilst fresh air enters through appropriate channels, to supply its place.

There can be no doubt, but that what is termed the vacuum method, is by far the most simple and easy of application, particularly for private houses, for fires and chimneys being employed for other purposes, no separate *apparatus* is needed; whereas a fan almost necessitates the accompaniment of a steam engine. In the case of mines and ships, where the air cannot be admitted from below, and all cases where large fires would require to be kept burning expressly for the purpose of generating a draft, a fan is both the most efficient and cheapest. For private dwelling-houses however, connecting the discharge openings with a chimney fulfils all the conditions required, provided there be an ample supply of fresh air admitted below; for the breath being discharged at a temperature of 98, rises rapidly to the ceiling by its own levity, and if proper provision be made for its escape, there is no danger of its descending to be breathed over again. This arrangement is in fact in harmony with the great system employed by nature for the ventilation of the lower and inhabited stratum of the atmosphere, which would otherwise speedily become contaminated by the exhalations from the living myriads which people it.

Objections have lately been urged against the vacuum system of ventilation, on the plea that the atmosphere of apartments so ventilated, will be kept constantly slightly more rarefied than the external air, and will therefore have a tendency to produce lassitude, and a relaxation of tone in those who breathe it, from the amount of oxygen being less in the same volume; whilst on the contrary, it is contended that air slightly condensed will have an opposite effect, and conduce to vigour and activity. M. Junot says, that "When a person is placed in condensed air, he breathes with increased facility, he feels as if the capacity of his lungs were enlarged; his respirations become deeper and less frequent; he experiences, in the course of a short time, an agreeable glow in his chest, as if the pulmonary cells were becoming dilated with an elastic spirit, while the whole frame receives at each inspiration a fresh vital impulse; the functions of the brain get excited, the imagination becomes vivid, and the ideas flow with a delightful facility; digestion becomes more active, as after gentle exercise in the air, because the secreting organs participate immediately in the increased energy of the arterial system, and there is therefore no thirst."

I confess, when first I read this statement, I felt a momentary sensation of regret, to think that the great bulk of the community should be debarred from participating in advantages so manifold, from the difficulty which I foresaw in the general application of the fan to private dwellings, on account of the motive power required. A very slight consideration however sufficed, to enable me to perceive that nothing could be more chimerical than these ideas, and that to hold out any such results as being attainable by any practicable scheme of ventilation, was only imposing an illusion on the public. Those, therefore, who have a thirst to arrive at perfection in all things, need not disquiet themselves under the apprehension that they must be content to forego this desirable object with regard to ventilation, unless they are prepared to keep a piece of machinery constantly in motion for its attainment. Had the propounders of this notable scheme, given themselves the trouble to realize the details, I imagine the public would never have heard of it.

Air, under the pressure of ·04 of an inch of water, has the velocity of a pleasant breeze, or $9\frac{1}{2}$ feet per second. Supposing a house charged with air under this pressure, the opening of the door for half a minute, would give egress to 6000 cubic feet of air, provided the rate of supply were equal to maintain the pressure during the period. I think, from these considerations, it will be apparent that, without complicated contrivances for keeping the building in a state approximating to being hermetically sealed, a much higher pressure than this could not be practically maintained. Assuming then, ·04 of an inch of water to be the pressure, the condensation of the air would only amount to $\frac{1}{11000}$ of its volume, whilst the variation of *only* 1° *in temperature*, would produce 22 times this effect.

In short, the association of "the excited brain, the vivid imagination, the flowing ideas," with the breathing of air condensed $\frac{1}{11000}$, is infinitely ridiculous—an illusion, which can only find an abiding-place in a brain where such a state of pleasing exaltation is combined with a paralysis of judgment. Equally absurd and preposterous, with the encomiums lavished upon the *plenum* method of ventilation, is the condemnation that has been passed upon that by *vacuum*, under the mistaken notion, that it gives rise to a variety of injurious effects, quite beyond its power to produce. We have but to invert our argument, to perceive, that as little injury is to be apprehended from the rarefaction of air by $\frac{1}{11000}$ of its volume, as there is benefit to be hoped for, from this amount of condensation.

All the evils however that have been erroneously attributed to the method of ventilation by vacuum, are, I believe, justly assignable to the system of warming by heated air. Here, we get an amount of rarefaction capable of producing a decided physical influence, for air at 45° contains nearly $\frac{1}{16}$ more oxygen in the same bulk, than air at 75°. Thus we see, that a variation in temperature of only 30°, produces nearly as great a change of volume, as is effected by a difference of pressure equivalent to 2 inches of mercury, or 27 inches of water.

When we consider, that when the air is perfectly still in winter, and the thermometer at 32° in the shade, a person can stand still, with comfort in the sunshine, without feeling cold, it is plain that *inhaling warm air into the lungs*, is quite unnecessary to maintain the body at an agreeable temperature, and fulfil the requirements of our instinctive sensations.

In short, other conditions being equal, the colder the air breathed, the better will the temprrature of the body be maintained, since the increased quantity of oxygen taken into the lungs, will generate an additional quantity of heat, more than sufficient to compensate for the increased refrigeration consequent upon the lower temperature of the air inhaled, besides which, the evaporation from the lungs will be less. Therefore, the colder the weather, the colder requires to be the air for respiration, and the *colder nature has provided it*, but we exert ourselves to defeat her arrangements, and in this, as in other cases, are made to pay a penalty for our ignorance If we would take a lesson out of her book, and study the care she has taken to prevent the inhalation of *heated air* by animated beings; in the first place, by the law, that rays of heat pass through the atmosphere without being absorbed; in the second, by imparting to it a levity. which effectually prevents the possibility of its accumulation in the lower stratum of the atmosphere, when heated by *contact* with the earth's surface, we should surely pause, before deciding upon conducting the arrangements for warming the interior of our dwellings, upon principles exactly the reverse, of those she has provided for our benefit, by such unerring and irrevocable laws, as long as we remain denizens of her free domain.

In short, I conceive the present system of warming buildings by currents of heated—and therefore, necessarily, rarified—air, to be fundamentally erroneous, and one which ought to be abandoned, as injurious to health. The diminished quantity of oxygen taken into the lungs, diminishes the energy with which all the vital functions are carried on; the carbon in the blood is imperfectly burnt, and less heat generated in consequence; creating a craving for a larger supply of artificial heat than would be required, were the atmosphere inhaled denser, and consequently richer in oxygen; whilst the habitual dependence upon, and necessity for, artificial heat thus engendered, enfeebles the constitution, and deprives it of its powers of resisting cold with impunity; produces a general and unnatural susceptibility to take cold,* and suffer from slight draughts, deranges the func-

* The lungs being designed by nature for the inhalation of cold air, find in it their appropriate stimulus to action, whilst their functions languish in an artificially heated atmosphere. Neither is the pernicious influence of the adoption of such unnatural appliances, confined to those who become enervated by their habitual use. On the contrary, those who are brought by the exigencies of travel, or business, or the intercourse of social life, even temporarily within their sphere, are often severe sufferers. If, after lengthened exposure to cold, the body being at rest, (say on the outside of a coach, or in a railway carriage,) the individual gradually restores the heat of the body by muscular exercise, he will be pretty sure to escape a cold—the same may be said if he goes to bed, and seeks refuge in good warm blankets. Even if he indulges himself with an apartment *moderately* heated by an open fire, he may stand a fair chance of escape; but should he on the contrary, be so unfortunate as to become an inmate of a room, the atmosphere of which is kept at a high temperature, by currents of heated air, rarely indeed will he escape with impunity. Probably never, *if* the *amount* of cold induced, has been really such, as much to depress his nervous system, for when the diameter of the capillary arteries of the air passages has been long contracted by cold, and their nervous energy expended, their power of contractility being weakened, they become *relaxed* beyond their power of immediate spontaneous recovery, by the too *sudden* exposure to heat, and a *catarrh* is the result—a disease, which is to the lungs, what chilblains are to the hands and feet—and arises from the same cause, viz. the *too rapid application of heat after exposure to cold.*

Should any one find himself committed to a journey, and inadequately clothed, so as to experience an uncomfortable degree of cold, let him by no means seek distraction from the sensation, by endeavouring to absorb the mind in some intellectual operation, either by following out some train of thought, or immersing himself in a book, for, by so doing, *the chances of taking cold are doubled.* In such a position, the whole of the nervous energy, as fast as generated by respiration, is required to protect the outworks of the citadel against the enemy—cold; and all that is consumed in the intellectual operations carried forward, is so much subtracted from this (for the time being) more essential duty. Under such circumstances, the mind should be withdrawn from all extraneous objects of distraction, and concentions of the skin, and begets a liability to the attacks of consumption and other diseases of the respiratory organs, and a delicate state of the health generally, to which persons who pass much time in the open air, and do not resort to these pernicious contrivances for unnaturally rarefying the atmosphere of their dwellings, but, on the contrary, allow free ingress to fresh cold air, are total strangers.

I have repeatedly observed the complexion of those who inhabit apartments heated by closed stoves, and hot air, to be peculiarly sallow and unhealthy, and have, on inquiry, generally learnt that the state of the health corresponded, and that they were extremely susceptible of taking cold; in short, they resemble delicate hot-house plants, liable to be nipped and destroyed by a single night's exposure; whilst, on the other hand, butchers, agriculturists, and others, who carry on their avocations in the open air, have ruddy complexions, with all their vital functions robust and vigorous.

If the example of nature is to be copied, and made our rule of practice, then the only adjunct to the radiation from the fire (the sun of the apartment) should be the warming the walls, whilst the fresh air necessary for ventilation should be admitted cold. Rays of heat being radiated on all sides, the occupants may be made comfortable, and the thermometer kept at any point desired; but inasmuch as rays of heat pass through air without heating it, it will, under such circumstances, no more indicate the temperature of the air, than a thermometer in the sunshine, which stands at 100°, whilst the surrounding atmosphere is only 32°. To heat and ventilate an apartment, I should propose to surround the lower half with canvas, behind which the air from the atmosphere* should enter freely, and

trated within itself. The painful sensation of cold, must, in short, be made the object of attention, and actively resisted as an enemy. So effectually have some individuals the power of doing this, that I have known persons who could always resist catching cold whilst awake.

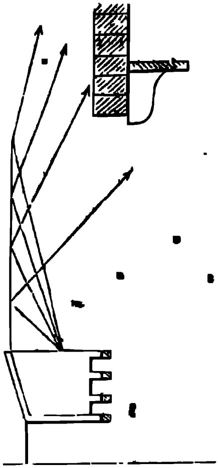
Whoever will attend to the hints contained in this note, will be amply repaid for the trouble of perusing this small volume, for I venture to say that two more important maxims for the preservation of health, than those just enunciated, do not exist.

* The orifice through which the supply of air for ventilation is drawn, should always be situated above the vapour line of the locality, or the air which enters at night, may be of a poisonous quality, particularly in malarious districts.

pass into the room through the minute subdivisions between the threads. Above the canvas, should be a hollow chamber, extending the remaining height of the walls, round which the products of combustion should be carried, and dismissed into a chimney at the opposite end from the fireplace, with which the apparatus for the escape of the vitiated air should also communicate. When large and lofty assembly rooms have to be heated, a chamber above the ceiling, might also be put in communication with the side flues, and thus constitute a hot air reservoir, and in certain cases it might be expedient to construct a hot air chamber beneath the floor, like the hypocaustum of the ancients. Apartments so warmed would not be subject to the vicissitudes and alternations of temperature inherent in the present system. The heat from the fire by day, would endure all night, so that in the coldest weather, the room would not be chilly in the morning, or require the heat getting up for an hour or two, before being comfortably habitable, as is now the case. From the free admission of the fresh air all round the sides of an apartment, and *the large extent of surface* provided for its entrance, its diffusion would be effected without the possibility of local draughts, and, at the same time, there would be a delightful freshness and elasticity in the atmosphere, resembling that of the open air, and the antipodes of the rarefied, enervating, oppressive, and noxious medium, with which our public buildings and other similarly heated edifices are at present polluted.

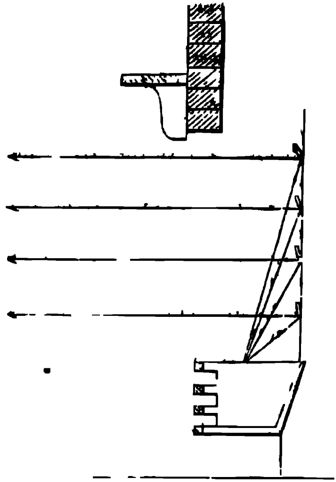
A vast deal has been written as to the proper angle the jambs should form with the back of the chimney, so as to reflect the largest amount of heat, but strange to say, the subject has generally been treated of, as if the jambs were on a *level* with the sides of the fire, instead of being placed *above* it, and thus the very satisfactory looking diagrams showing a horizontal section of the fire and jambs, with the angle of reflection, delineated in many books on the subject, exhibit a state of things applicable only to the lower portion of the jambs, where they are on a level with the surface of the fire; directly they rise above this, they reflect the rays of heat progressively more and more *upwards*, first towards the ceiling, and then up the chimney, instead of horizontally *outward*, into the apartment, as will be manifest from an inspection of the diagram on the following page.

Fig 1.



Shewing the direction in which rays of heat from the centre of the fire, are reflected by the *ordinary jamb, with a plain surface.*

Fig. 2.



Shewing the direction in which rays of heat from the centre of the fire, are reflected by the *horizontal ribbed jamb with gradually encreasing angle.*

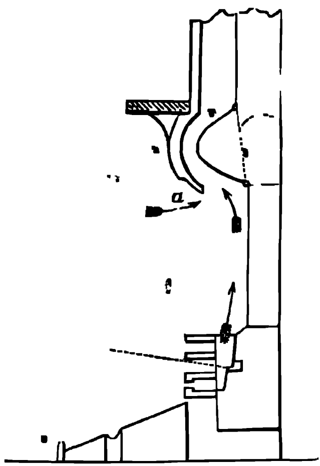
To obviate this great loss of heat, I propose to construct the jambs of a series of reflecting surfaces arranged in horizontal strips, somewhat resembling Venetian blinds, the inclination of each increasing slightly from below upwards, in such a ratio, that each shall reflect a ray of heat proceeding from the centre of the fire, horizontally outwards, into the apartment. These reflectors may be made either of polished brass, or steel, and if of the latter, may be advantageously set in zinc, that so, being rendered negative, oxydation or rust may be prevented, and their brightness preserved. Fig. 2, represents such a reflecting jamb in vertical section, with lines shewing the angles at which the rays of heat are reflected, and by contrasting the direction of these lines, with the same lines in fig 1, a section of an ordinary jamb, with a plain surface, the vast superiority as a heat reflector of the horizontally ribbed jamb, which I propose to substitute for it, will be at once apparent.

The point, next of importance to the perfection of a grate, is to close over the area between the top of the jambs, and above the fire, *in such a manner*, that in the first place, *as large a portion as possible of the heat radiated by the fire directly upwards, as well as of the heat contained in the ascending current of the products of combustion, shall be absorbed, and again radiated downwards, instead of being allowed to pass away into the chimney ;* and in the second place, *that the passage of a current of cold air above the fire up the chimney, be, as far as practicable prevented.* This current, being formed of the pure air in the lower part of the room, is comparatively useless as far as ventilation is concerned, even in an apartment badly ventilated; whilst, if the room be provided (as should be deemed indispensable), with one of the admirable ventilators of Dr. Arnot, or some equivalent contrivance opening into the chimney just below the ceiling, the due ventilation of the apartment, consisting of the flow of the vitiated air from its upper part into the chimney, would be positively impeded by the entrance of the cold current from below. In addition to being useless or prejudicial as far as ventilation is concerned, this current of air towards the fire, is productive of much discomfort to individuals sitting around it, by producing a cold draught against their backs, whilst the heat, carried off by it up the chimney, is so great as seriously to impair the power of the fire to warm the apartment.

Both the above desiderata may be attained by the same arrangement, and in an easy, simple, and complete manner. The area between the upper portion of the jambs, should be closed by a plate commencing at the back, and running upwards at an angle of about 30°, to a point about 3 inches above the lower edge of the chimney breast. The front edge of the plate should be connected with the chimney breast at the sides, but left open in the middle, for a space equal to the breadth of the fire, for the passage of the products of combustion up the chimney.

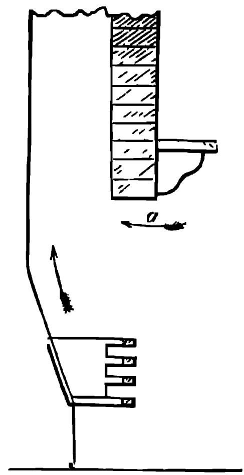
By this arrangement, in the first place no heat can be radiated by the fire directly up the chimney, on the contrary all radiated in this direction will be either directly reflected back, or absorbed and re-radiated; in the second place, instead of the current of the heated products of combustion passing straight up the chimney, and carrying off all the heat with which it is charged, it is previously made to *impinge* on an absorbing surface which abstracts a portion of its heat before its dismissal; in the third place, instead of a stream of cold air from the room, being allowed to pass directly upwards, and backwards, into the chimney, the forward direction given to the heated current from the fire, will almost entirely prevent the passage of any. An inspection of the diagrams below, will enable the reader to judge of the relative effects of the two systems.

Fig. 3.



Shewing that when the breast of the chimney is closed by a plate opening in front, instead of at the back, or in the middle, so as to incline the heated current from the fire *forwards*, before its passage up the chimney, the rush of cold air up this aperture, cooling the room and producing a draught against the backs of the individuals sitting round the fire is prevented; no draught can evidently take place in the direction of the arrow *a* in this figure, whilst a powerful one must necessarily exist at this point in figure 4.

Fig. 4.



Given as a contrast to figure 3, being the arrangement of the chimney of the room in which I am now writing, and such is the ignorance of the public on the subject, far from an uncommon one, although the facility for the passage of a large volume of cold air up the chimney is so great, that with the consumption of four times the quantity of fuel that ought to be required, the apartment is still inadequately warmed, whilst the larger the fire, the greater the draught of cold air against the backs of persons sitting round it.

The plate should either be formed of two pieces of sheet iron joined at the edges, with a space of about an inch between the sheets filled with cinder dust, so as to be rendered a bad conductor of heat, or else of a large stout tile or slate. Chimneys have usually been made sloping backwards, under the erroneous impression that such a plan was necessary to prevent liabilty to smoke, the general ignorance prevailing amongst the public at large, of the simple laws of pneumatics, by which the motion of heated currents of air is determined, having invested the subject of smoky chimneys with a mystery, difficulty, and uncertainty, which in reality are far from belonging to it; the conditions, by the observance of which, freedom from smoke may be attained, being simple of apprehension, easy of application, and invariable in their result.*

If any one, who has a fire place on the old construction, with a wide yawning chimney, opening directly upwards, or, still worse, upwards and backwards, from the fire, will try the experiment of closing the breast of the chimney in the manner I have described, they will be astonished at the result, and find, to their surprise, that with half the quantity of coals, the heating effect of the fire, on the apartment, will be doubled. I can speak authoritatively on the point, for I speak from experience.

* Chimneys smoke when the force of the ascending current is overcome by the force of the downward draught; strengthen the former, and diminish the latter, and the smoke will ascend. The most common cause of a chimney smoking is from its being made too large, this occasions the velocity of the ascending current to be slow, and *its force on a given area small, from its great diffusion*, and it is consequently unable to overcome the force of descending draughts. Another cause which frequently comes into operation, particularly with small rooms, is the want of a sufficiently free and constant ingress of air to the room, steadily to supply the quantity abstracted by the chimney. This defect may be remedied by bringing a supply of air for the fire, from the external atmosphere by a pipe terminating beneath the grate; a plan which has the further advantage of preventing the draught, which otherwise sets towards the fire, sweeping the floor of the room, keeping the feet cold, and necessitating a fire of twice the dimensions which would otherwise be adequate to heat the apartment, and this with no benefit to the ventilation, since the air carried off is the cold and freshly entered lower stratum of air, instead of the upper heated and impure. The cases most difficult of cure are those where some higher object in the vicinity of the chimney top, offers a surface against which the wind impinges, and becomes deflected down the chimney. Rows of houses built beneath high cliffs have sometimes in particular winds, all their chimneys simultaneously affected from this cause.

ON THE VENTILATION OF COAL MINES.

At the present moment, when the recent sad and appalling loss of life in coal mines, is directing public attention towards the subject of the ventilation of collieries, the following estimate of the relative efficiency of a given weight of coal in producing power—1st, when applied through the instrumentality of a steam engine, and 2ndly, when employed to rarefy a column of air, and thus impart to it an ascending force—will probably be regarded with interest.

Before entering into any calculation on the subject, I *felt* that the having recourse to the comparatively inert agency of gravity, acting through the ascentional tendency of a column of heated air, must be a wasteful mode of obtaining power, when compared with the expedient of employing for this purpose, the vastly more energetic force developed by the chemical law of vaporisation upon the addition of heat to a liquid, as in the case of converting water into steam. I was not however prepared for the actual results which presented themselves, viz. that 1lb of coals employed to raise steam in a Cornish steam engine, will do the work of 100lbs. expended in rarefying air—such air to be discharged through a shaft 100 feet in height, and to commence the ascent at a temperature of 568°.

Extraordinary as the above results may appear, the case on behalf of the steam engine is rather under stated, the *actual duty performed* by many of the Cornish engines, being above that assumed as the basis of this calculation. On the other side of the question on the contrary, no allowance is made for imperfect combustion, but the heating power of coal is calculated from that which the recent experiments of Andrews have assigned to carbon, viz. that 1 part will raise 14,220 parts of water 1°, whilst the specific heat of air is called ·25, that of water being 1.

These facts clearly shew that, even in circumstances where great depth of shaft presents the most favourable conditions for the use of rarefied air as the ventilatory force, coal so applied, must ever remain much less effective, than when employed in a Cornish engine. When, in addition to the small amount of duty obtained from coal as a ventilating agent, through the medium of a simple furnace, it is considered that precisely as the air of the mine becomes foul, and a larger supply is needed, does the action of the fire languish, and its powers of draught become diminished; and also, that there is reason to believe, that in many cases the ventilating furnace instead of being a safeguard, is itself the torch which kindles the conflagration; the superiority of a steam engine, on the *surface*, over a furnace, at the *bottom* of the shaft, is tolerably manifest.

The greatest element of danger in well ventilated collieries (because most difficult to guard against), is the accumulation of fire-damp in what are technically called *goafs*, which are in reality domes or caverns above the level of the ordinary workings, where the fire-damp, being lighter than air, remains detained beyond the reach of the ordinary ventilating current, just as air would be detained in an inverted tea-cup plunged below the surface of water. When, from a sudden fall in the barometer or any other cause, the contents of this reservoir of explosive matter descend, and mingle with the air of the mine, fearful catastrophes, of which we have recently had so many distressing examples, often occur. No efficient plan for the ventilation of these goafs has, so far as I am aware of, ever been suggested; but when a steam engine is employed to produce the upcast current, the same engine might, without difficulty, be made to exhaust the fire-damp from a goaf, by the agency of a gutta percha tube, to be conveyed to the highest point of the cavity; and thus these dangerous magazines of explosive matter, which rest, so to speak, primed and loaded, liable at any moment to descend upon, and overwhelm, the unfortunate workmen—would never be allowed to accumulate.

By causing the air exhausted from a goaf to pass through a species of gauge, which should indicate its specific gravity and temperature, before it escaped into the atmosphere (which might be easily arranged), the proportion of fire-damp in the air passing, might at all times be shewn, and thus the nature of the atmosphere in the mine *below*, be made perceptible at the *surface*.

When, as is often the case, large quantities of fire-damp are discharged from limited areas, it must I think, strike every one who reflects on the subject, that the method of abstracting this noxious agent by drawing it through the galleries commingled with the general ventilating current which supplies the lungs of the workmen, thus polluting the whole atmosphere of the mine, is a clumsy and unscientific procedure, intrinsically incapable of satisfactorily fulfilling the objects, for which ventilation is employed.