The effect of a blow-pipe is well known, but I do not think that the *manner* in which it increases the *action* of *Flame* has ever been satisfactorily explained. It has generally been imagined, I believe, that the current of fresh air which is forced through the Flame by a blow-pipe actually increases the quantity of heat; I rather suppose it does little more than direct the heat *actually existing in the Flame* to a given point. A current of air cannot *generate* heat, without at the same time being decomposed; and in order to its being decomposed in a fire, it must be brought into actual contact with the burning Fuel, or at least with the uninflamed inflammable vapour which rises from it:—But can it be supposed that there can be any thing inflammable, and not actually inflamed, in the clear, bright, and perfectly transparent Flame of a wax candle?—A blow-pipe has however as sensible an effect when directed against the clear Flame of a wax candle, as when it is employed to increase the action of a common glass-worker's lamp.

Conceiving that the discovery of the *manner* in which the current of air from a blow-pipe serves to increase the intensity of the action of the Flame could not fail to throw much light upon the subject under consideration,—namely, the investigation of *the manner* in which heat is communicated to bodies by Flame,—I made the following Experiments, the results of which I conceive to be decisive.

Concluding that the current of air from a blow-pipe, directed against the Flame of any burning body, could tend to increase the intensity of the action of the Flame only in one or both of these two ways, namely, by increasing its *action* upon the body against which it is directed; or by actually increasing the *quantity* of heat generated in the combustion of the Fuel; a method occurred to me by which I thought it possible to determine, by actual experiment, to which of these causes the effect in question is owing, or how much each of them might contribute to it. To do this I filled a large bladder, containing above a gallon, with *fixed air*, which, as is well known, is totally unfit for supporting the combustion of inflammable bodies, and which, of course, could not be suspected of *adding* any heat to a Flame against which a current of it should be directed; I imagined therefore that if a blow-pipe supplied with this air, on being directed against the Flame of a candle, should be found to produce nearly the same effect as when common air is used for the same purpose, it would prove to a demonstration that the augmentation of the intensity of the action, or activity of the Flame which arises from the use of a blow-pipe, is owing to the agitation of the Flame,—to its being directed to a point,—to the impetuosity with which it is made to strike against the body which is heated by it,—and to the rapid succession of fresh particles of this hot vapour, and not to any *positive increase of heat*,

A blow-

A blow-pipe being attached to the bladder containing fiexd air, the end of this pipe was directed to the clear brilliant flame of a wax candle, which had juſt been ſnuffed; and, by compreſſing the bladder, the Flame was projected againſt a ſmall tube of glaſs, which was very ſoon made red-hot, and even melted.

Having repeated this experiment ſeveral times, and having found how long it required to melt the tube when the Flame of the candle was forced againſt it by a blaſt of *fixed air*, I now varied the experiment, by making uſe of common atmoſpheric air, inſtead of fixed air; taking care to employ the ſame candle and the ſame blow-pipe uſed in the former experiments, and even making uſe of the bladder, in order that the experiments being exactly ſimilar, and differing only in the kinds of air made uſe of, the effect of that difference might be diſcovered and eſtimated.

The reſults of theſe experiments were moſt perfectly concluſive; and proved in a deciſive manner, that the effect of a blow-pipe, *when applied to clear Flame*, ariſes not from any real augmentation of heat, but merely from the increaſed activity of the Flame, in conſequence of its being impelled with force, and broken in eddies on the ſurface of the body againſt which it is made to act; the effect of the blow-pipe on theſe experiments being to all appearance quite as great when fixed air was made uſe of, (which *could not* increaſe the quantity of heat,) as when atmoſpheric air was uſed.

 But

But conceiving the determination of this queſtion relative to the manner in which Flame communicates heat, to be a matter of much importance, I did not reſt my inquiries here: I repeated the experiments very often, and varied them in a great number of different ways; ſometimes making uſe of fixed air; ſometimes of atmoſpheric air; and at other times uſing dephlogiſticated air; and common air rendered unfit for the ſupport of animal life and of combuſtion, by burning a candle in it till the candle went out.

It would take up too much time to give an account in detail of all theſe experiments; I ſhall therefore content myſelf with merely obſerving that they all tended to ſhow that the effect of a blow-pipe *uſed in the manner here deſcribed*, is owing to the direction and velocity it gives to the Flame againſt which it is employed, and not to any real increaſe of heat.

It muſt be remembered that the principal object I had in view in theſe experiments was to diſcover the *manner* in which Flame communicates heat to other bodies, and by what means that communication may be facilitated.—Were it required to increaſe the intenſity of the heat by *blowing the fire*, the current of air muſt be applied in ſuch a manner as to expedite the combuſtion; it muſt be directed to the inflamed ſurface of the burning Fuel, and not to the red-hot vapour or flame which riſes from it, and in which the combuſtion is moſt probably already quite complete; and in this caſe there is no no doubt but the effect produced by blowing would depend much upon the quality of the air made use of.

The results of the foregoing experiments with the blow-pipe will, I am confident, be thought quite conclusive by those who will take the trouble to consider them attentively,—and the advantages that may be derived from the knowledge of the fact established by them are very obvious. If Flame, or the hot vapour which arises from burning bodies, be a non-conductor of heat;—and if, in order to communicate its heat to any other body, it be necessary that its particles *individually* be brought into actual contact with that body; it is evident that the form of a boiler, and of its fire-place, must be matters of much importance; and that *that form* must be most advantageous, which is best calculated to produce an internal motion in the Flame, and to bring alternately as many of its particles as possible into contact with the body which is to be heated by it. The boiler must not only have as large a surface as possible, but it must be of such a form as to cause the Flame which embraces it—to impinge against it with force—to break against it—and to play over its surface in eddies and whirlpools.

It is therefore against the *bottom* of a boiler, and not against its sides, that the principal efforts of the Flame must be directed; for when the Flame, or hot vapour, is permitted to rise freely by the vertical sides of a boiler, it slides over its surface very rapidly, and there being no obstacle in the way to break

break the Flame into eddies and whirlpools, it glides quietly on like a ſtream of water in a ſmooth canal; and the ſame hot particles of this vapour which happen to be in immediate contact with the ſides of the boiler at its bottom or lower extremity, being continually preſſed againſt the ſurface of the boiler as they are forced upwards by the riſing current, prevent other hot particles from approaching the boiler; ſo that by far the greateſt part of the heat in the Flame and hot vapour which riſe from the Fire, inſtead of entering the boiler, goes off into the atmoſphere by the chimney, and is totally loſt.

The amount of this loſs of heat, ariſing from the faulty conſtruction of boilers and their fire-places, may be eſtimated from the reſults of the Experiments recorded in the following Chapter.

CHAP. V.

An Account of Experiments made with Boilers and Fire-places of various Forms and Dimensions; together with Remarks and Observations on their Results, and on the Improvements that may be derived from them.—An Account of some Experiments made on a very large Scale in a Brew-house Boiler.—An Account of a Brew-house Boiler constructed and fitted up on an improved Plan.—Results of several Experiments which were made with this new Boiler.—Of the Advantage in regard to the Economy of Fuel in boiling Liquids, which arises from performing that Process on a large Scale.—These Advantages are limited.—An Account of an Alteration which was made in the new Brew-house Boiler, with a view to the SAVING OF TIME *in causing its Contents to boil.—Experiments showing the Effects produced by these Alterations.—An Estimate of the* RELATIVE QUANTITIES OF HEAT *producible from* COAKS—PIT-COAL—CHARCOAL, *and* OAK.—*A Method of estimating the Quantity of Pit-coal which would be necessary to perform any of the Processes mentioned in this Essay, in which Wood was used as Fuel.—An Estimate of the* TOTAL QUANTITIES *of Heat producible in the Combustion of different Kinds of Fuel; and of the real Quantities of Heat*

Heat which are lost, under various Circumstances, in culinary Processes.

WHAT has been said in the foregoing Chapter will, I trust, be sufficient to give my reader a clear and distinct idea of the subject under consideration, in all its various details and connections,—and enable him to comprehend, without the smallest difficulty, every thing I have to add on this subject; and particularly to discover the different objects I had in view in the Experiments of which I am now about to give an account, and to judge with facility and certainty of the conclusions I have drawn from their results.

These Experiments, though they occupy so many pages in this Essay, are but a small part of those I have made, and caused to be made under my direction, on the subject of Heat, during the last seven years. Were I to publish them all, with all their details as they are recorded in the register that has been kept of them, they would fill several volumes.

It was most fortunate for me that this register is very voluminous; for had it not been so, I should in all probability have taken it with me to England last year, and in that case I should have lost it, with the rest of my papers, in the trunk of which I was robbed in passing through St. Paul's Church-yard, on my arrival in London after an absence of eleven years *.

* I have many reasons to think that these papers are still in being;—what an everlasting obligation should I be under to the person who would cause them to be returned to me!

As

As I foresaw, when I first began my inquiries respecting Heat, that I should have occasion to make many Experiments on boiling Liquids, to facilitate the registering of them I formed a Table, (which I had printed,) in which, under various heads, every circumstance relative to any common Experiment of the kind in question could be entered with much regularity, and with little trouble.

As this Table may be useful to others who may be engaged in similar pursuits, and as the publishing of it will also tend to give my reader a more perfect idea of the manner in which my Experiments were conducted, I shall (as an example) give an account of one Experiment, *in the same form* in which it was registered in one of these printed Tables.

These Tables, as they are printed for use, (on detached sheets,) occupy one side of half a sheet of common folio writing-paper.

AN EXPERIMENT ON THE MANAGEMENT OF FIRE IN BOILING LIQUIDS;
Made at [MUNICH], in [a Brew-houſe belonging to the Elector], the [15th] of [April 1795].

Time of the Day.		Fuel put into the Fire-place.		Temperature of the Liquid.	Contents of the Boiler.		
Hour.	Minutes.	Numb. of Pieces.	In Weight.		Kind of Liquid, &c.	Meaſures.	In Weight.
			lbs.				lbs.
9	.15	29	100	60°	[Water].	6984	12508
—	30	6	50	70°			
—	41	6	50	—			
10	5	7	50	92°			
—	25	7	50	105°			
—	46	7	50	120°			
11	0	7	50	130°			
—	15	7	50	—			
—	26	8	50	145°			
—	43	7	50	155°			
—	50	7	50	163°			
12	5	8	50	173°			
—	17	7	50	183°			
—	31	15	100	192°			
—	55	—	—	[boiled].			
1	38	7	50	—			
2	35	7	50	—			
3	38	—	—	[ceaſed boiling].			

Height of the Barometer, $26\frac{5}{12}$ Inches; of Thermometer, 58°.

DIMENSIONS OF THE BOILER.

Diameter { above —— or long —— 10 Feet.
below —— and wide —— 8 Feet.

Deep, 4 Feet.—Was conſtructed of [Copper], and weighed [not known]; contained of Water 8176 Meaſures, weighing 14643 lbs.

KIND OF FUEL USED.—[Pine-wood, Moderately dry, in Lengths of 6 Feet.]

GENERAL RESULTS OF THE EXPERIMENT.

		h.	min.
Time employed to make the Liquid boil,	—	[3	40]
Fuel conſumed to make the Liquid boil,	—	[800]	lbs.
		h.	min.
Time the Liquid continued to boil,	— —	2	43
Fuel added to keep the Liquid boiling,	—	100	lbs.

Quantity of the Liquid evaporated [not obſerved].

PRECISE RESULT.

With the Heat generated in the Combuſtion of 1 lb. of the Fuel,
[13.23 lbs.] of ice-cold Water made to boil;
or [339.80 lbs.] of boiling-hot Water kept boiling 1 Hour.

Every thing in this Table, except ſuch figures and words as are printed between crotchets, is contained in the printed forms: Hence it is evident how much theſe Tables tend to diminiſh the trouble of regiſtering the reſults of Experiments of this kind, and alſo to prevent miſtakes.

The example I have here given is an account of an Experiment, in which a very large quantity of water, equal to 15,590 lbs. Avoirdupois in weight, or 1866 wine gallons of 231 cubic inches each, was uſed; but it is evident that theſe tables anſwer equally well for the ſmall quantity contained by the ſmalleſt ſaucepan.

The height of the barometer is expreſſed in Paris inches; that of the thermometer in degrees of Fahrenheit's ſcale.—The other meaſures, as well of length as of capacity, are the common meaſures of the country (Bavaria); and the weight is expreſſed in Bavarian pounds, of which 100 make 123.84 lbs. Avoirdupois.

What is entered under the head of GENERAL RESULTS OF THE EXPERIMENT, requires no explanation; but what I have called the PRECISE RESULT muſt be explained.

Having frequent occaſion to compare the reſults of Experiments made at different times and in different ſeaſons of the year, as the temperature of the water in the Boiler when the fire is lighted under it is ſeldom the ſame in any two Experiments, and as the boiling heat varies with the variations of the preſſure of the atmoſphere, or of the height of the mercury in the barometer, it became neceſſary to make proper allowances for theſe differences. This I thought could beſt be done by determining, by computation, from the number of degrees the water was *actually heated*, and the quantity of Fuel conſumed in heating it that number of degrees, how much Fuel would have been required to have it heated 180 degrees, or from the point of freezing to that of boiling water (the boiling point being taken equal to the temperature indicated by 212° of Fahrenheit's thermometer, which is the boiling point under the mean preſſure of the atmoſphere at the ſurface of the ſea): Then, by dividing the weight of the water uſed in the Experiment, (expreſſed in pounds,) by the weight of the Fuel expreſſed in pounds neceſſary to heat it 180 degrees, or from the temperature of freezing to that of boiling water; this gives the number of pounds of ice-cold water which (according to the reſult of the given Experiment) *might have been* made to boil,— with the heat generated in the combuſtion of 1 lb. of the Fuel, under the mean preſſure of the atmoſphere at the level of the ſurface of the ſea.

The city of Munich, where all the Experiments were made of which I am about to give an account, being ſituated almoſt in the centre of Germany, lies very high above the level of the ſea. The mean height of the mercury in the barometer is only about 28 Engliſh inches, conſequently water boils at Munich at a lower temperature than at London. The difference is even too conſiderable

to

to be neglected, it amounts to 2½ degrees of Fahrenheit's scale,—being 209½ degrees at a medium at Munich, and 212 degrees in all places situated near the level of the sea. To render the results of my experiments and computations more simple and more generally useful, I shall always make due allowance for this difference.

Having, from the actual result of each Experiment, made a computation on the principles here described, showing what (for the want of a better expression) I have called the *Precise Result* of the Experiment, it is evident that these computations show very accurately the comparative merit of the mechanical arrangements, and the management of the Fire in conducting the Experiments, in as far as relates to the Economy of Fuel; for the more ice-cold water that can be made to boil with the heat generated in the combustion of any given quantity (1 lb. for instance) of Fuel, the more perfect of course (other things being equal) must be the construction of the fire-place.

Under the head of PRECISE RESULT I have sometimes added another computation, showing how much "*boiling-hot water*" might, according to the result of the given Experiment, be *kept boiling* "*one hour*" with the heat generated in the combustion of "1 lb. of the Fuel." Though I have called this a *Precise Result*, it is evident that in most cases it cannot be considered as being very exact, owing to the difficulty of estimating the quantity of Fuel in the fire-place, which is *unconsumed at the moment when the water begins to boil*.

 In

In the foregoing example in making this computation I fuppofed that, when the water began to boil, there was wood enough in the fire place *unconfumed* to keep the water boiling 43 minutes, and that the wood added afterwards (100 lb.) kept the water boiling the remainder of the time it boiled, or juft 2 hours.

In moft cafes, however, to fave trouble in making thefe computations, I have fuppofed that all the wood employed in making the water boil is entirely confumed in that procefs, and that all the heat expended in *keeping the water boiling* is furnifhed by the Fuel which is added *after the water had begun to boil.* This fuppofition is evidently erroneous; but as the computation in queftion can at beft give but an inaccurate and doubtful refult, labour beftowed on it would be thrown away: But imperfect as thefe rough eftimates are, they will however in many cafes be found ufeful.

In giving an account of the following Experiments, I fhall not place them exactly in the order in which they were made, but fhall arrange them in fuch a manner as I fhall think beft, in order that the information derived from their refults may appear in a clear point of view.

For greater convenience in referring to them, I fhall number them all; and as I have already given numbers to the four I mentioned in the Firft Chapter of this Effay, I fhall proceed in regular order with the reft.

Experiment, No. 5.

The firſt kitchen of the Houſe of Induſtry at Munich has already been deſcribed in the Firſt Chapter of this Eſſay; and it was there mentioned, that the daily expence of Fuel in that kitchen, when food (peas-ſoup) was prepared for 1000 perſons, amounted to 300 lb. in weight of dry beech-wood. Now as each portion of ſoup conſiſted of 1 lb., this gives 0.3 of a pound of wood for each pound of ſoup.

Experiment, No. 6.

The firſt kitchen of the Houſe of Induſtry having been pulled down, it was afterwards rebuilt on a different principle. Inſtead of Copper Boilers, Iron Boilers of a hemiſpherical form were now uſed, and each of theſe Boilers had its own ſeparate cloſed fire-place. The Boiler being ſuſpended by its rim in the brick-work, and room being left for the flame to play all round it. The ſmoke went off into the chimney by an horizontal canal, 5 inches wide and 5 inches high, which was concealed in the maſs of brick-work, and which opened into the fire-place on the ſide oppoſite to the opening by which the Fuel was introduced.

The Fire was made on a flat iron grate placed directly under the Boiler, and diſtant from its bottom about twelve inches. The aſh-pit door was furniſhed with a regiſter; but there was no damper to the canal by which the ſmoke went off into the chimney, which was a very great defect. The opening into the fire-place was cloſed by an iron door. Each of theſe Iron Boilers weighed about 148 lbs. Avoirdupois, was 25¾ Engliſh inches in diameter, and 14.935 inches deep, and contained 190½ lbs. Bavarian weight of water, equal to 235.91 lbs. Avoirdupois, or about 28¼ Engliſh wine-gallons.

From this account of the manner in which theſe Iron Boilers were fitted up, it is evident that the arrangement was not eſſentially different from that of kitchens for hoſpitals, as they are commonly conſtructed.

From Experiments made with care, and often repeated, I found that to prepare 89 portions (or 89 lbs. Bavarian weight) of peas-ſoup in one of theſe Boilers, 43 lbs. of *dry beech-wood* were required as Fuel, and that the proceſs laſted four hours and an half: This gives 0.483 of a pound of wood for each pound of the ſoup.

In the firſt arrangement of this kitchen, only 0.3 of a pound of wood was required to prepare 1 lb. of ſoup: Hence it appears that the kitchen had not been improved,—conſidered with a view to the Economy of Fuel,—by the alterations which had been made in it. This was what I expected; for the object I had in view in conſtructing this kitchen was not to ſave Fuel, but to find out how much of it is waſted in culinary proceſſes, as they

they are commonly performed on a large ſcale in hoſpitals and other inſtitutions of public charity.— Till I knew this, it was not in my power to eſtimate, with any degree of preciſion, the advantages of any improvements I might introduce in the conſtruction of kitchen fire-places.

To determine in how far the quantity of Fuel neceſſary in any given culinary proceſs depends on the form of *the fire-place*, (the Boiler and every other circumſtance remaining the ſame,) I made the following Experiments.

Experiments, No. 7 *and* No. 8.

Two of the Iron Boilers in the kitchen of the Houſe of Induſtry (which, as they were both caſt from the ſame model, were as near alike as poſſible) being choſen for this Experiment, one of them (No. 8.) being taken out of the brick-work, its fire-place was altered and fitted up anew on improved principles. The grate was made circular and concave, and its diameter was reduced to 12 inches; the fire-place was made cylindrical above the grate, and only 12 inches in diameter; and the Boiler being ſeated on the top of the wall of this cylindrical fire-place, the flame paſſing through a ſmall opening on one ſide of the fire-place, at the top of it, made one complete turn about the Boiler before it was permitted to go off into the canal by which the ſmoke paſſed off into the chimney.

 Though

Though there was no damper in this canal, yet as its entrance or opening, where it joined the canal which went round the Boiler, was confiderably reducèd in fize, this anfwered (though imperfectly) the purpofe of a damper. This fire-place being completed, and a fmall Fire having been kept up in it for feveral days to dry the mafonry, the Experiment was made by preparing the fame quantity of the fame kind of foup in this, and in a neighbouring Boiler whofe fire-place had not been altered.

The food cooked in each was 89 lb. of Peas-foup; and the Experiment was begun and finifhed in both Boilers at the fame time.

The wood employed as Fuel was pine; and it had been thoroughly dried in an oven the day before it was ufed.

The Boilers were both kept conftantly covered with their double covers, except only when the Soup was ftirred about to prevent its burning to the bottoms of the Boilers.

The refult of this interefting Experiment was as follows:

	Experiment No. 7. In the Boiler No. 1.	Experiment No. 8. In the Boiler No. 8, with the improved Fire-place.
Quantity of wood confumed in cooking 89 lbs. Bavarian weight of Peas-foup - - - - - - - - -	37 lbs.	14 lbs.

Thefe

These Experiments were made on the 7th of November 1794. On repeating them the next day with pine-wood, which had not been previously dried in an oven, the result was as follows:

Experiments, No. 9 *and* No. 10.

	Experiment No. 9. In the Boiler No. 1.	Experiment No. 10. In the Boiler No. 8, with the improved Fire-place.
Quantity of wood consumed in cooking 89 lbs. of Peas-soup - - -	39 lbs.	16 lbs.

The first remark I shall make on the results of these Experiments is the proof they afford, by comparing them with that which preceded them (No. 6.), of the important fact, that pine-wood affords more heat in its combustion than beech. This fact is the more extraordinary, as it is directly contrary to the opinion generally entertained on that subject; and it is the more important, as the price of pine-wood is, in most places, only about half as high as that of beech, when the quantities, *estimated by weight*, are equal.

In the Experiment No. 6. it was found, that 43 lb. of dry beech-wood were necessary, when used as Fuel,. to prepare 89 lbs. of Peas-soup. In the Experiment No. 7. the same process was performed with 37 lb. and in the Experiment No. 9. with

with 39 lb. of dry pine. But I ſhall have occaſion to treat this ſubject more at length in another place. In the mean time I would, however, juſt obſerve, that all my Experiments have uniformly tended to confirm the fact, that dry pine-wood affords more heat in combuſtion than dry beech. I have reaſon to think the difference is in fact greater than the Experiments before us indicate; but the *apparent* amount of it will always depend in a great meaſure on the circumſtances under which the Fuel is conſumed; or, in other words, on the conſtruction of the fire-place; and it is no ſmall advantage attending the fire-places I ſhall recommend, that they are ſo contrived as to increaſe, as much as it is poſſible, the ſuperiority of the moſt common and cheapeſt fire-wood over that which is more ſcarce and coſtly.

By comparing the reſults of theſe two ſets of Experiments (No. 7 and No. 8, No. 9 and No. 10.) an eſtimate may be made of the advantage of uſing *very dry wood* for Fuel, inſtead of making uſe of wood that has been leſs thoroughly dried; but as I mean to take an opportunity of inveſtigating that matter alſo more carefully hereafter, I ſhall not at preſent enlarge on it. farther than juſt to obſerve, that as the wood, which was dried in an oven, was weighed for uſe after it had been dried, and as it certainly weighed more before it was put into the oven, the real ſaving ariſing from uſing it in this dried ſtate is not ſo great as the difference in the weights of the quantities of wood uſed in the two Expe-

Experiments. To eſtimate that ſaving with preciſion, the wood ſhould be weighed before it is dried, or in the ſame ſtate in which the other parcel of wood, which is uſed without being dried, is weighed.

But to proceed to the principal object I had in view in theſe Experiments;—the determination of the effects of the difference in the conſtruction of the two fire-places;—the difference in the quantity of Fuel expended in the two-fire-places in performing the ſame proceſs, ſhows, in a manner which does not ſtand in need of any illuſtration, how much had been gained by the improvements which had been introduced.

Conceiving it to be an object of great importance to aſcertain by actual experiment, and with as much preciſion as poſſible, the real amount of the advantages, in regard to the Economy of Fuel, that may be derived from improvements in the forms of fire-places, I did not content myſelf with improving from time to time the kitchens I had conſtructed, but I took pains to determine how much I had gained by each alteration that was made. This was neceſſary, not only to furniſh myſelf with more forcible arguments to induce others to adopt my improvements, but alſo to ſatisfy myſelf with regard to the progreſs I made in my inveſtigations.

In the firſt arrangement of the kitchen of the Military Academy, the Boilers were ſuſpended by their rims in the brick-work in ſuch a manner that the

the flame could paſs freely all round them, and the ſmoke went off in horizontal canals which led to the chimney, but which were not furniſhed with dampers.

The Fire was made on a flat ſquare iron-grate; and the internal diameter of the fire-place was 2 or 3 inches larger than the diameter of the Boiler which belonged to it. The bottom of the Boiler was from 6 to 10, or 12 inches (according to its ſize) above the level of the grate; and the door of the opening into the fire-place, by which the Fuel was introduced, was kept conſtantly cloſed. The aſh-pit door was furniſhed with a regiſter, and the Boilers were all furniſhed with double covers.

Having, in conſequence of the progreſs I had made in my inquiries reſpecting the Management of Heat and the Economy of Fuel, come to a reſolution to pull down this kitchen, and rebuild it on an improved principle; previous to its being demoliſhed, I made ſeveral very accurate Experiments to determine the real expence of Fuel in the fire-places as they *then exiſted*, with all their faults; and when the new arrangement of the kitchen was completed, I repeated theſe Experiments *with the ſame boilers;* and by comparing the reſults of theſe two ſets of Experiments, I was able to eſtimate with great preciſion the real amount of the ſaving of time as well as of Fuel,—which were derived from the improvements I had introduced.

After all that has been ſaid (and perhaps already too often repeated in different parts of this Eſſay) on on the conſtruction of fire-places, my reader will be able to form a clear and juſt idea of the conſtruction of thoſe of which I am now ſpeaking, (thoſe of the kitchen of the Military Academy, in its *preſent* improved ſtate,) when he is told that the Fire burns on a circular concave iron grate, about half the diameter of the circular Boiler which belongs to the fire-place; that the fire-place, properly ſo called, is a cylindrical cavity in the ſolid brick-work which ſupports the Boiler, equal in diameter to the circular grate, and from ſix to ten inches high, more or leſs according to the ſize of the Boiler; that the Boiler is *ſet down* on the top of the circular wall which forms this fire-place, a ſmall opening, from three to four or five inches in length taken horizontally, and about two or three inches high, being left on one ſide of this wall at the top of it, that the flame which burns up under the middle of the bottom of the Boiler may afterwards paſs round (in a ſpiral canal conſtructed for that purpoſe) under that part of the bottom of the Boiler which lies *without* the top of the wall of the fire-place on which the Boiler repoſes. The flame having made one complete turn *under* the Boiler in this ſpiral canal, it riſes upwards, and going once *round the ſides of the boiler*, goes off by an horizontal canal, furniſhed with a damper, into the chimney.

In order that the top of the circular wall of the fire-place on which the Boiler is ſeated, may not cover too much of the bottom of the Boiler, its thickneſs is ſuddenly reduced *in that part* (that is to ſay juſt where it touches the Boiler) to about half an inch.

The opening by which the Fuel is introduced into the fire-place, is a conical hole in a piece of fire-ſtone, which hole is cloſed by a fit ſtopper made of the ſame kind of ſtone. The aſh-pit door and its regiſter are finiſhed with ſo much nicety, that when they are quite cloſed the Fire almoſt inſtantaneouſly goes out.

The dimenſions of the Boiler, in which the Experiments of which I am about to give an account were made, are as follows:

Diameter	above	14.935	Inches, Engliſh meaſure.
	below	13.39	
Depth		14.52	

It weighs 37 lbs. Avoirdupois; and it contains, when quite full, about 73 lbs. Avoirdupois, equal to 8¾ gallons (wine-meaſure) of water.

In two Experiments with this Boiler, which were both made by myſelf, and in which attention was paid to every circumſtance that could tend to render them perfect, the reſults were as follows:

	Experiment No. 11. The firſt Fire-place.	Experiment No. 12. The improved Fire-place.
Quantity of Water in the Boiler, in *Bavarian pounds* - - - -	43.63 lbs.	43.63 lbs.
Temperature of the water in the Boiler at the beginning of the Experiment - - - - - - -	59°	60°
Time employed in making the water boil - - - - - - -	67 min.	30 min.
Wood conſumed in making the water boil, in *Bavarian pounds* -	9 lbs.	3 lbs.
Time the water continued boiling - - - - - - - - - -	2 hrs. 2 min.	3 hours
Wood added to keep the water boiling - - - - - - - -	5 lbs.	2 ½ lbs.
Kind of wood uſed - - - -	Pine	Pine
Preciſe Reſults.		
Ice-cold water heated 180 degrees, or made to boil, with 1 lb. of wood - - - - - - - -	4.02 lbs.	11.93 lbs.
Boiling-hot water kept boiling 1 hour, with 1 lb. of wood -	17.74 lbs.	52.36 lbs.

The

The following Experiments were made with two Copper Boilers, (No. 1 and No. 2.) nearly of the fame dimenfions, in the kitchen of the Military Academy at Munich, in the prefent improved ftate of that kitchen. Thefe Boilers are round and deep, and weigh each about 62 lbs. Avoirdupois. They belonged originally to the kitchen of the Houfe of Induftry, being two of the eight Boilers which, in the firft arrangement of that kitchen, were heated by the fame Fire.

Their exact dimenfions, meafured in Englifh inches, are as follows:

	The Boiler No. 1.	The Boiler No. 2.
	Inches.	Inches.
Diameter above —	22.66	22.66
Diameter below —	19.82	20.85
Depth — — —	24.72	22.04

At the beginning of each of the following Experiments, each of thefe Boilers contained juft 95 meafures (or *Bavarian maaffe*) of water, weighing 187 lbs. Bavarian weight, (equal to 232.58 lbs. Avoirdupois,) or a trifle lefs than 28 gallons.

The grate on which the Fire was made under each of thefe Boilers is circular and concave, and 11 inches in diameter; and their fire-places are in all refpects fimilar to that juft defcribed (Experiment No. 11.). Both Boilers are furnifhed with double covers.

The

The Experiments made with the Boiler No. 1. and their refults, were as follows:

	Experiment No. 13.	Experiment No. 14.	Experiment No. 15.	Experiment No. 16.
Quantity of water in the Boiler in the beginning of the Experiment - - -	lbs. 187	lbs. 187	lbs. 187	lbs. 187
Temperature of the water in the Boiler at the beginning of the Experiment -	61°	59°	64°	55½°
Time employed in making the water boil - - - - -	min. 78	min. 61	min. 61	min. 62
Wood confumed in making the water boil - - - - -	lbs. 12	lbs. 11	lbs. 9	lbs. 8
Time the water continued to boil - -	min. 17	min. 28	min. 6	h. min. 2 19
Quantity of Fuel added to keep it boiling this time - -	—	—	—	lbs. 4
Kind of wood ufed as Fuel - - - -	Beech	Beech	Pine	Pine
Precife Refults of the Experiments.				
Ice-cold water heated 180°, or made to boil, with the heat generated in the combuftion of 1 lb. of the Fuel - -	lbs. 12.89	lbs. 14.15	lbs. 16.89	lbs. 20
Boiling water kept boiling one hour, with the heat generated in the combuftion of 1 lb. of the wood - - - -	—	—	—	lbs. 108.40

All

All the foregoing Experiments were made on the ſame day, (the 13th of October 1794,) and in the ſame order in which they are numbered.

The following are the reſults of the Experiments made with the Boiler No. 2.

	Experim. No. 17.	Experim. No. 18.	Experim. No. 19.	Experim. No. 20.	Experim. No. 21.
Quantity of water in the Boiler at the beginning of the Experiment, in *Bavarian pounds* —	lbs. 187	lbs. 187	lbs. 187	lbs. 187	lbs. 187
Temperature of the water in the Boiler at the beginning of the Experiment — —	61°	58°	60°	55°	212°
Time employed in making the water boil —	min. 75	min. 55	min. 57	min. 60	—
Wood conſumed in making the water boil —	lbs. 11	lbs. 11	lbs. 9	lbs. 8	—
Time the water continued to boil — —	min. 21	min. 17	min. 8	h. min. 2 29	h. min. 1 10
Wood added to keep the water boiling — —	lb. 1	—	—	lbs. $3\frac{1}{2}$	lbs. $1\frac{1}{2}$
Kind of wood uſed —	Beech	Beech	Pine	Pine	Beech
Preciſe Reſults.					
Ice-cold water heated 180°, or made to boil, with 1 lb. of wood —	lbs. 13.92	lbs. 14.33	lbs. 17.59	lbs. 20.10	—
Boiling-hot water kept boiling one hour with 1 lb. of wood — —	—	—	—	lbs. 132.68	lbs. 145.44

This ſet of Experiments was made at the ſame time with the foregoing ſet, namely, on the 13th October 1794, and they were made in the order in which they are here regiſtered. In the laſt but one, (No. 20.) the Economy of Fuel in the proceſs of heating water was carried farther than in any other Experiment I have ever made.

In

In the following Experiments, which were made in a large Copper Boiler fitted up on my moſt improved principles, belonging to the kitchen of the Houſe of Induſtry, the Economy of Fuel was carried nearly as far.

This Boiler, which is circular, is 42½ Engliſh inches in diameter above; 42.17 inches in diameter below; and 18.54 inches deep. It weighs 78½ lbs. Avoirdupois; and contains, when quite full, 714 lbs. *Bavarian weight* (= 884 lbs. Avoirdupois, or 106 gallons) of water, at the temperature of 55°.

It is ſurrounded above by a wooden ring about two inches in thickneſs, into which it is fitted; and in this ring, in a groove about ¾ of an inch deep, is fitted a circular wooden flat cover; this cover is formed in three pieces, united by iron hinges; and one of theſe pieces being faſtened down by hooks to the Boiler, the other two are ſo contrived as to be folded back upon it occaſionally. From the upper ſurface of the part of the cover which is faſtened down on the Boiler, a tin tube two inches in diameter, furniſhed with a damper, is fixed, by which the ſteam is carried off into a narrow wooden tube, which conducts it through an opening in the roof of the houſe into the open air.

To prevent ſtill more effectually the eſcape of the Heat through the wooden cover of the Boiler, the upper ſurface of it is protected from the cold atmoſphere by a thick circular blanket covered on both ſides by ſtrong canvas, which is occaſionally thrown over it.

 Though

Though the diameter of this Boiler below is more than 40 inches, the diameter of its fire-place (which is juſt under its centre) is only 11 inches; but as the flame makes two complete turns under the bottom of the Boiler in a ſpiral canal, and one turn round it, the time required to heat it is not ſo great as, from the ſmallneſs of its fire-place, might have been expected.

It has ever been, and ſtill continues to be, the decided favourite of the cook-maids.

The wood uſed as Fuel in the following Experiment was pine moderately dried. The billets were ſix inches long, and from one to two inches in diameter.

The following Table ſhows the reſults of five Experiments that were made with this Boiler by myſelf, juſt after it was fitted up:

	Experim. No. 22.	Experim. No. 23.	Experim. No. 24.	Experim. No. 25.	Experim. No. 26.
Quantity of water in the Boiler, in Bavarian pounds — — —	lbs. 508	lbs. 127	lbs. 254	lbs. 508	lbs. 508
Temperature of the water at the beginning of the Experiment —	48°	48°	96°	48°	48°
Time required to make the water boil — —	h. min. 2 4	min. 51	h. min. 1 15	h. min. 2 35	h. min. 3 1
Fuel employed to make the water boil — —	lbs. $24\frac{1}{3}$	lbs. $8\frac{1}{4}$	lbs. $12\frac{3}{4}$	lbs. 25	lbs. 24
Time the water continued boiling — —	h. 3	—	—	h. 3	—
Fuel added to keep the water boiling — —	lbs. $6\frac{12}{32}$	—	—	lbs. $4\frac{1}{2}$	—
PRECISE RESULTS *of the Experiments.*					
With the heat generated in the combuſtion of 1 lb. of the Fuel,					
Ice-cold water heated 180°, or made to boil	lbs. 18.37	lbs. 12 74	lbs. 12 69	lbs. 17.48	lbs. 15.01
Or boiling-hot water kept boiling one hour	236.61.	—	—	338.66	—

Without

Without ſtopping to make any obſervations on the reſults of theſe Experiments, (though they afford matter for ſeveral of an intereſting nature,) I ſhall proceed to give a brief account of another ſet of Experiments, on a much larger ſcale, which were made in the Copper Boiler of a Brewery belonging to the Elector.

This Boiler, which is rectangular, is ten feet long, eight feet wide, and four feet deep, *Bavarian meaſure* *, and contains 8176 *Bavarian maaſſe*, or meaſures, equal to 1866 gallons wine meaſure. On examining this Boiler, I found its fire-place was conſtructed on very bad principles; and on inquiring reſpecting the quantity of fire-wood conſumed in it, I found the waſte of Fuel to be very great.

This Brewery is uſed for making ſmall *white* beer, (as from its pale colour it is called,) from malt made of wheat; and as it is worked all the year round, the expence of Fuel was very great, and the economy of it an object of conſiderable importance.

The quantity of fire-wood (pine) that had at an average been conſumed daily in this Brewery was rather more than four Bavarian *clafters*, or cords. On altering the fire-place of this Brewery, and putting a (wooden) cover to the Boiler, I reduced this expence to leſs than 1½ clafters.

In the new fire-place which I cauſed to be conſtructed for this Boiler, the cavity under the Boiler

* 100 Bavarian inches are equal to 95¾ inches Engliſh meaſure.

is divided into three flues, by thin brick walls which run in the direction of the length of the Boiler. The middle flue, which is twice as wide as one of the ſide flues, is occupied by the burning Fuel, and is furniſhed with a grate 20 inches wide, and 56 inches long; and the opening by which the Fuel is introduced into the fire-place is cloſed by two iron doors, placed one behind the other, at the diſtance of eight inches. The grate, which is placed at the hither end of the fire-place, is horizontal, and it is ſituated about twenty inches below the bottom of the Boiler. The air which ſerves to feed the Fire, is let in under the grate through a regiſter in the aſh-pit door.

When the double doors which cloſe the entrance into the fire-place are ſhut, the flame of the burning Fuel firſt riſes perpendicularly againſt the bottom of the Boiler; it then paſſes along to the farther end of the (middle) flue, which conſtitutes the fire-place, where it ſeparates, and returns in the two ſide flues; it then riſes up into two horizontal flues (one ſituated over the other) which go all round the Boiler; and having made the circuit of the Boiler, it goes off into ſeparate canals (furniſhed with dampers) into the chimney.

Though the Figures 17 and 18, Plate III. are not drawings from the fire-place I am now deſcribing, but of another which I ſhall ſoon have occaſion to deſcribe, yet an inſpection of theſe figures will be found uſeful in forming an idea of the principles on which the fire-place in queſtion was conſtructed, and

and on that account I ſhall occaſionally refer to them.

The burning Fuel being confined within a narrow compaſs,—being well ſupplied with freſh air,—and being ſurrounded on all ſides by thin walls of brick, (which are non-conductors,) the heat of the fire is moſt intenſe, and the combuſtion of the Fuel of courſe very complete. The flame, which is clear and vivid in the higheſt degree, and perfectly unmixed with ſmoke, runs rapidly along the bottom of the Boiler, (which forms the top of the flues,) and from the reſiſtance it meets with in its paſſage, from friction, and from the number of turns it is obliged to make, it is thrown into innumerable eddies and whirlpools, and really affords a moſt entertaining ſpectacle.

That I might be able to enjoy at my eaſe this amuſing ſight, I cauſed a glaſs window to be made in the front wall of the fire-place, through which I could look into the Fire when the fire-place doors were ſhut; and I was well paid for the trouble and the trifling expence I had in getting it executed.

Some may be tempted to ſmile at what they may think a childiſh invention; but there are many others, I am confident, and among theſe many grave philoſophers, who would have been very glad to have ſhared my amuſement.

The window of which I am ſpeaking is circular, and only ſix inches in diameter; but as the hole in the wall is conical, and much larger within than without, the field of this window (if I may uſe the

 expreſſion)

expreſſion) is ſufficiently large to afford a good view of what paſſes in the fire-place.

This conical hole is repreſented in the Figures 18 and 21, by dotted lines. It is ſituated on the left hand of the entrance into the fire-place. Into the opening of the hole in the wall, on the outſide of it, is fixed a ſhort tube of copper, (about ſix inches in diameter, and four inches long,) and in this tube another ſhort *moveable* tube is fitted, one end of which is cloſed by the circular plate of glaſs which conſtitutes the window. As the wall of the fire-place in front is thick, this pane of glaſs is at a conſiderable diſtance from the burning Fuel, and as there is no draught through the hole in the wall, the glaſs does not grow very hot.

I have been the more particular in my deſcription of this little invention, as I think it may be uſeful: There are many caſes in which it would be very advantageous to know exactly what is going on in a cloſed fire-place; and this never can be known by opening the door; for the inſtant the door is opened, the cold air ruſhing with impetuoſity into the fire-place, deranges entirely the whole economy of the Fire: Beſides this, it is frequently very diſadvantageous to the proceſs which is going on, to open the door of a fire-place; and it is always attended with a certain loſs of heat, and conſequently ſhould as much as poſſible be avoided.

I intimated that the window I have been deſcribing afforded me amuſement;—it did ſtill more,—it afforded me much uſeful information;—it gave me an an opportunity of *obſerving* the various internal motions into which flame may, by proper management of the machinery of a fire-place, be thrown; and of eſtimating, with ſome degree of preciſion, their different effects. In ſhort, it made me better acquainted with the ſubject which had ſo long engaged my attention—(Fire);—and with regard to *that* ſubject, nothing ſurely that is new can be unintereſting. But to return to the Brewery:—To the top of the Boiler was fitted a curb of oak timber: The four ſtraight beams of which this curb was conſtructed are each about 7 inches thick, and 15 inches wide; and the upper part of the Boiler is faſtened by large copper nails to the inſide of the ſquare frame formed by theſe four beams. From the top of this curb is raiſed a wooden building, like the roof of a houſe with a double ſlant or bevel, which ſerves as a cover to the Boiler. This building, the ſides of which are about three feet high inwards, and the top of which is covered in by a very flat roof, ſlanting on every ſide from the centre,—is conſtructed of a light frame-work of timber, (four-inch deal joiſts,) which is covered within as well as without with thin deal boards, which are rabbetted into each other at their edges, to render the cover which this little edifice forms for the Boiler as tight as poſſible.

From the top of this cover, an open wooden tube, (*m*, Fig. 17.) about 12 inches in diameter, riſes up perpendicularly, and going through the roof of the Brewhouſe, ends in the open air. This tube,

tube, which is furniſhed with a wooden damper, is intended to carry off the ſteam.

On the ſide of this cover next the maſhing-tub, as alſo on that oppoſite to it, by which the wort runs off into the coolers, there are large folding wooden doors, (*i* and *k*, Fig. 17.) which are occaſionally lifted up by means of ropes which paſs over pullies faſtened to the ceiling of the Brewhouſe.

There are likewiſe two glaſs windows (ſee Fig. 17.) in two oppoſite ſides of the cover, through which, as ſoon as in conſequence of the boiling of the liquid the ſteam becomes tranſparent and *inviſible*, (which happens in a very few minutes after the liquid has begun to boil,) the contents of the Boiler may be diſtinctly ſeen and examined.

Whenever there is occaſion during the boiling to open either a door or a window of the cover, it is neceſſary to begin by opening the damper of the ſteam-chimney, otherwiſe the hot ſteam, ruſhing out with violence, would expoſe the by-ſtanders to the danger of being ſcalded; but when the damper of the ſteam-chimney is open, no ſteam comes into the Brewhouſe, though a door or window of the cover be wide open.

Another ſimilar precaution is ſometimes neceſſary in opening the door of the fire-place, which it may be uſeful to mention.—When the dampers in the canals by which the ſmoke goes off into the chimney are nearly cloſed, (which muſt frequently be done to confine and economiſe the heat,) if, without altering the damper, or the regiſter in the

aſh-

aſh-pit door, the fire-place door be ſuddenly opened, it will frequently happen that ſmoke, and ſometimes flame, will ruſh out of the fire-place by this paſſage. This accident may be eaſily and effectually prevented, either by opening the damper, or by cloſing the regiſter of the aſh-pit door, the moment before the fire-place door is opened.—This precaution ſhould be attended to in all fire-places of all dimenſions, conſtructed on the principles I have recommended.

To economiſe the time and the *patience* of my reader as far as it is poſſible, without ſuppreſſing any thing eſſential relating to the ſubject under conſideration, I ſhall give him, in a very ſmall compaſs, the general reſults of a ſet of Experiments which coſt me more labour (or at leaſt more *time*) than it would coſt him to read all the Eſſays I have ever written. I believe I am ſometimes too prolix for the taſte of the age,—but it ſhould be remembered that the ſubjects I have undertaken to inveſtigate are by no means indifferent to me;—that I conceive them to be intimately connected with the comforts and enjoyments of mankind;—and that a habit of revolving them in my mind, and reflecting on their extenſive uſefulneſs, has awakened my enthuſiaſm, and rendered it quite impoſſible for me to treat them with cold indifference, however indifferent or tireſome they may appear to thoſe who have not been accuſtomed to view them in the ſame light.

I have

I have already given an account, in all its various details, of one Experiment which was made (on the 15th of April 1795) with the Boiler we have juſt been deſcribing (ſee page 78). I ſhall now recapitulate the general reſults of that Experiment, and compare them with the mean reſults of two other like Experiments made with the ſame Boiler.

	Experiment No. 27.	Experiment No. 28.
Quantity of water in the Boiler -	12,508 lbs.	12,508 lbs.
Temperature of the water in the Boiler at the beginning of the Experiment - - - - - - -	60°.	58°
Time required to make the water boil - - - - - - - - -	3 h. 40 min.	3 h. 48 min.
Fuel employed to make the water boil - - - - - - - - -	800 lbs.	825 lbs.
Time the water continued boiling - - - - - - - - -	2 h. 43 min.	—
Fuel added to keep the water boiling - - - - - - - -	100 lbs.	—
Kind of Fuel uſed - - - - -	Pine-wood	Pine-wood
PRECISE RESULTS of the Experiments.		
Quantity of *ice-cold water* which might be heated 180°, or made to boil, with the heat generated in the combuſtion of 1 *lb. of the Fuel* - - - - - -	12.06 lbs.	12.70 lbs.
TIME in which, according to the reſult of the Experiment, *ice-cold water* might (at Munich) *be made to boil* with the given proportion of Fuel - - - -	4 h. 20 min.	4 h. 20 min.
Quantity of *boiling-hot water kept boiling one hour* with the heat generated in the combuſtion of 1 lb. of the Fuel -	339.80 lbs.	—

On

On comparing the refults of thefe Experiments with thofe made in the Boilers of the kitchens of the Houfe of Induftry and Military Academy, I was led to imagine that either the Boiler, or the fire-place of the Brewery, or both, were capable of great improvement; for in fome of the Experiments with thefe fmall kitchen Boilers, the Economy of Fuel had been carried fo far, that with the heat generated in the combuftion of 1 lb. of pine-wood, it appeared that 20 lbs. of ice-cold water might have been made to boil; but here, though the machinery was on a fcale fo much larger, (and I had concluded, too rafhly indeed, as will be fhown hereafter, that the larger the Boiler the greater is of courfe the Economy of Fuel,)—the refults of thefe Experiments indicated, that not quite 13 lbs. of ice-cold water could have been made to boil with the heat furnifhed in the combuftion of 1 lb. of the wood.

The Experiments, No. 22, No. 25, and No. 26, which were made with the largeft of my kitchen Boilers, had, it is true, afforded grounds to fufpect that, beyond certain limits, an increafe of fize in a Boiler does not tend to diminifh the expence of Fuel in the procefs of heating water; yet, as all my other Experiments had tended to confirm me in the opinion I had, at an early period, imbibed on that fubject, I was difpofed to fufpect any other caufe than the true one of having been inftrumental in producing the unexpected appearances I obferved.

I was

I was much diſappointed, I confeſs, at finding that the Brewhouſe Boiler, notwithſtanding all the pains I had taken to fit up its fire-place in the moſt perfect manner, and notwithſtanding its enormous dimenſions, when compared with the Boilers I had hitherto uſed in my Experiments, ſo far from anſwering my expectations, actually required conſiderably more Fuel, in proportion to its contents, than another Boiler fitted up on the ſame principles, which was not *one fiftieth* part of its ſize.

This unexpected reſult puzzled me;—and I muſt own that it vexed me, though I ought perhaps to be aſhamed of my weakneſs;—but it did not diſcourage me. Finding on examining the Boiler, that its bottom was very thick, compared with the thickneſs of the ſheet copper of which my kitchen Boilers were conſtructed, it occurred to me that poſſibly *that* might be the cauſe, or at leaſt *one of the cauſes*, which had made the conſumption of Fuel ſo much greater than I expected; and as there was another Brewhouſe in the neighbourhood belonging to the Elector, which, luckily for me, ſtood in need of a new Boiler, I availed myſelf of that opportunity to make an Experiment, which not only decided the point in queſtion, but alſo eſtabliſhed a new fact with regard to heat, which I conceive to be of conſiderable importance.

Having obtained the Elector's permiſſion to arrange the ſecond Brewhouſe as I ſhould think beſt, I determined to ſpare no pains to render it as perfect as poſſible in all reſpects, and particularly in

every

every thing relating to the Economy of Fuel. As in brewing, in the manner that buſineſs is carried on in Bavaria, where the whole proceſs, in as far as Fire is employed in it, is begun and finiſhed in the courſe of a day, *the ſaving of time*, in heating the water and boiling the wort, is an object of almoſt as much importance as that of economizing Fuel, and conſequently demanded particular attention.

The means I uſed for the attainment of both theſe objects will be evident from the following deſcription of the Boiler and its fire-place, which I cauſed to be conſtructed, and which are repreſented in all their details in the Plates III, IV, and V.

This Boiler is 12 (Bavarian) feet long, 10 feet wide, and only 2 feet deep. The ſheet copper of which it is made is uncommonly thin for a Boiler of ſuch large dimenſions, being at a medium leſs than *one-tenth* of an Engliſh inch in thickneſs. This Boiler, when finiſhed, weighed no more than 674 lbs. Bavarian weight, equal to 834¾ lbs. Avoirdupois, excluſive of 64 lbs. of copper nails uſed in rivetting the ſheets of copper together.

The top of the Boiler is ſurrounded by a ſtrong curb (*a*, *b*, Fig. 17.) of oak timber, to which it is attached by ſtrong copper nails, and over the Boiler is built a roof, or ſtanding cover, (ſee Fig. 17.) ſimilar in all reſpects to that already deſcribed. The bottom of the Boiler is flat, and repoſes horizontally on the top of the thin brick walls by which the fire-place is divided into flues. (See Fig. 18.)—Theſe flues do not run in the direction of the length

of

of the Boiler, but from one ſide of it to the other;—conſequently the door of the fire-place is in the middle of one ſide of the Boiler.

The ſheets of copper, of which the bottom of the Boiler was conſtructed, run in the direction of the flues; and they are juſt ſo wide that their ſeams or joinings (where they are united to each other by their ſides) repoſe on the walls of the flues, except only in the middle flue, which, being about twice as wide as the others, one ſeam was neceſſarily left unſupported, at leaſt a conſiderable part of its length.—The ſheets of copper uſed in conſtructing this part of the bottom of the Boiler are rather thicker and ſtronger than the reſt: They are juſt 0.118 of an Engliſh inch in thickneſs.

The fire is made under this Boiler in the middle flue, which, as I have juſt obſerved, is a little more than twice as wide as one of the other flues. There are *five* flues under the Boiler; namely, one in the middle 44 inches wide, above, in the clear, (which conſtitutes the fire-place,)—and *two* on each ſide of it, in which the flame circulates; one 20 inches wide, and the other 19 inches wide.

The ſide flues are each 14½ inches deep;—but as the walls which ſeparate them are much thicker below than above, where the bottom of the Boiler repoſes on them, the width of theſe flues below is only 13 inches.—The walls of theſe flues are ſhown by dotted lines in Fig. 17.

The walls which ſeparate the flues do not run quite from one ſide of the Boiler to the other; an opening being left at one end of each of them equal to the width of one of the narrow flues for the paſ-ſage of the flame from one flue into another, with-out its going from under the Boiler.

The Fire being made (on a circular grate) in the middle flue (ſee Fig. 18.), the flame paſſes on in this flue to its farther end, and then, dividing to the right and left, comes forward in the two ad-joining ſide-flues. Having arrived at the wall which ſupports the front of the Boiler, it turns again to the right and left; and, entering the two outſide flues, returns in them to the back of the Boiler. Here it went out (before the fire-place was altered) at two openings left for that purpoſe in the wall which ſupports the back part of the Boiler, and the two currents of flame uniting, entered a canal 7 inches wide, and 16 inches high, which goes all round the outſide of the Boiler. (See Fig. 20.) Having made the circuit of the Boiler, it went off by a canal (furniſhed with a damper) into the chimney.

From this deſcription of the fire-place, it appears that the flame and ſmoke generated in the com-buſtion of the Fuel in paſſing through thoſe dif-ferent flues, made a circuit of above 70 feet, in contact with the ſurface of the Boiler, before they were permitted to eſcape into the chimney. This I thought muſt be ſufficient to give theſe hot fluids an opportunity of communicating to the Boiler all the heat they could part with, notwithſtanding the difficulties which attend their getting rid of it: And I concluded that the communication of their heat

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to the Boiler would be much facilitated and expedited by the various eddies and whirlpools produced in the flame in consequence of the number of abrupt turns and changes of direction it was obliged to make in passing under and round the Boiler.

As the Experiments which have been made with this Boiler were conducted throughout with the utmost care and attention, and as their results are both curious and important in several respects, I have thought them deserving of being made known to the Public in all their details.

An Account of three Experiments made at Munich the 10th October 1796, with the new Boiler in the Brewery called *Neuheusel*, belonging to HIS MOST SERENE HIGHNESS the ELECTOR.—The weather being fair: The barometer standing at 28 English inches, and Fahrenheit's thermometer at 36°.

Dimensions of the Boiler, in English measure, as found by actual admeasurement,	Length	11 feet 6.02 inches,
	Width	9 — 7.723 ——
	Depth	2 — 0.205 ——

Contents of the Boiler, when quite full to the brim, 14,163 lbs. *Bavarian weight* of water, at the temperature of 55°, equal to 17,540lbs. Avoirdupois, or 2099 wine gallons.

The Boiler actually contained of water, in the beginning of each of the two following experiments, - - -	*in Bavarian weight* ——8120lbs.

equal to 10,056 lbs. Avoirdupois, or nearly 1204 wine gallons.

The wood used in this and the following Experiments was *Pine*, which had been moderately seasoned, and the billets were 3 feet 4¼ inches, English measure, in length.

FIRST

First Experiment with the new Boiler.

Experiment, No. 29.

Time.			Fire-wood put into the Fire-place.		Temperature of the water in the Boiler.
Hours.	Min.		Number of Billets.	Quantity in weight. lbs.	In degrees of Fahrenheit's Therm.
11	31	A. M.	10	50	50
—	46	—	15	25	54
12	0	—	5	25	64
—	10	P. M.	5	25	67
—	36	—	—	—	85
—	40	—	4	25	—
—	53	—	5	25	96
1	12	—	7	25	105
—	21	—	10	50	110
—	46	—	10	50	129
—	58	—	40	50	—
2	17	—	46	50	156
—	29	—	—	—	164
—	34	—	10	50	—
—	41	—	—	—	173
—	49	—	—	—	180
—	58	—	40	50	185
3	15	—	12	50	197
—	26	—	20	25	205
3	35	—	—	—	the water boiled.

Time employed, } 4 h. 4 min. Wood consumed, 575 lbs.

The

The boiling water being let off, and it being replaced immediately with cold water, the Experiment was repeated as follows:

Experiment, No. 30.

Time.			Quantity of Fire-wood put into the Fire-place.		Temperature of the water in the Boiler.
Hours.	Min.		Number of Billets.	Quantity in weight. lbs.	In degrees of Fahrenheit's Therm.
4	41	P. M.	40	50	60°
—	50	—	40	50	72
5	4	—	10	50	86
—	16	—	10	50	99½
—	29	—	10	50	114
—	42	—	10	50	126
—	56	—	40	50	142
6	10	—	40	50	157
—	24	—	40	50	—
—	28	—	—	—	172
—	40	—	40	50	—
—	42½	—	—	—	185½
—	53	—	40	50	—
—	55	—	—	—	198
7	2	—	—	—	205
7	7	—	—	—	the water boiled.

Time employed, } 2 h. 26 min. Wood consumed, 550 lbs.

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This boiling water being let off, the Boiler was again filled (immediately) with cold water; and in this third Experiment the quantity of water was increased to 11,368 lbs. *Bavarian weight*,—equal to 14,078 lbs. Avoirdupois, or 1685 wine gallons.

The results of this Experiment were as follows:

Experiment, No. 31.

Time.			Quantity of Fire-wood put into the Fire-place.		Temperature of the water in the Boiler.
Hours.	Min.		Number of Billets.	Quantity in weight. lbs.	In degrees of Fahrenheit's Therm.
8	51	P. M.	80	100	$65\frac{1}{2}°$
9	7	—	40	50	79°
—	21	—	40	50	90
—	44	—	40	50	107
—	57	—	40	50	118
10	14	—	40	50	130
—	28	—	40	50	140
—	45	—	40	50	155
11	—	—	40	50	165
—	15	—	40	50	175
—	30	—	40	50	182
—	45	—	40	50	200
11	58	—	—	—	the water boiled.

Time employed, } 3 h. 7 min. Wood consumed, 650 lbs.

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The following Table will ſhow the reſults of theſe three Experiments in a clear and ſatisfactory manner:

	Experiment No. 29.	Experiment No. 30.	Experiment No. 31.
Quantity of water in the Boiler at the beginning of the Experiment, in *Bavarian pounds* - - - -	8120 lbs.	8120 lbs.	11,368 lbs.
Temperature of the water at the beginning of the Experiment -	50°	60°	65½°
Time employed in making the water boil -	4 h. 4 min.	2 h. 26 min.	3 h. 7 min.
Fuel (Pine wood) conſumed in making the water boil, in *Bavarian pounds* - - - -	575 lbs.	550 lbs.	650 lbs.
Preciſe Reſults of the Experiments.			
Quantity of ice-cold water which might have been heated 180 degrees, or made to boil with the heat generated in the combuſtion of 1 lb. of the Fuel -	12.54 lbs.	12.28 lbs.	14.59 lbs.
Time in which, according to the reſult of the Experiment, ice-cold water might be made to boil at Munich with the given proportion of Fuel - - - - -	4 h. 31 min.	2 h. 59 min.	3 h. 35 min.

I was ſurpriſed, when I compared the reſults of theſe Experiments with thoſe made in the other Brewhouſe, Brewhoufe, to find how little in appearance I had gained by the alterations I had introduced; on a more careful examination of the matter, however, I found that I had gained much more than I at firft imagined, both in refpect to the Economy of Fuel, and to that of Time. The amount of thefe advantages will appear from the following comparifon of the mean refult of thefe two fets of Experiments:

	Precife Refults of the foregoing Experiments.	
	Quantity of ice-cold water made to boil with 1 lb. of the Fuel.	Time required to make ice-cold water boil, according to the refult of the given Experiment.
Firft Set.	lbs.	hrs. min.
In the Experiment No. 27. —	12.06	4 20
In the Experiment No. 28. —	12.70	4 20
Sum —	24.77	8 40
Means —	12.385	4 20
Second Set.		
In the Experiment No. 29. —	12.54	4 31
In the Experiment No. 30. —	12.28	2 59
Sum —	24.82	7 30
Means —	12.41	3 45

The mean refults of thefe two fets of Experiments differ very little from each other in appearance ; and from this circumſtance I ſhall prove, that the new Boiler is better adapted for ſaving Fuel than the old.

By comparing the reſults of the Experiments made with the ſame Boiler, but with different quantities of water, we ſhall conſtantly find that the expence of Fuel was *leſs* in proportion as the quantity of water was *greater*. In the Experiment No. 23, when 127 lbs. of water were uſed, the reſult of the Experiment indicated that no more than 12.74 lbs. of ice-cold water could be made to boil with the heat generated in the combuſtion of 1 lb. of the Fuel uſed ; but in the Experiment No. 26, made with the ſame Boiler, but when 4 times as much water was uſed, or 508 lbs., it appeared from the reſult of the Experiment, that 19.01 lbs. of ice-cold water might be made to boil with 1 lb. of the Fuel.

Now, in the firſt ſet of the Experiments we are comparing, as the quantity of water uſed (12,508 lbs.) was much greater than that uſed in the ſecond ſet (8120 lbs.), it is evident, that if the conſtruction of the machinery and the Management of the Fire had been equally perfect in the two caſes, the Economy of Fuel would have been greateſt where the largeſt quantity of water was uſed ;— that is to ſay, in the firſt ſet of Experiments ;—but, as that was not the caſe, it is certain that the Boiler uſed in the ſecond ſet is better adapted to economize Fuel than that uſed in the firſt.

But we need not go ſo far to ſearch for proofs of that fact. The reſult of the Experiment No. 31 is is alone sufficient to put the matter beyond doubt. In this Experiment, in which the quantity of water (though still considerably short of that used in the former set of Experiments) was augmented from 8120 lbs. to 11,368 lbs. the saving of Fuel was so much increased as to show in a decisive manner the superiority of the new boiler.

The Precise Results	Quantity of ice-cold water made to boil with 1 lb. of the Fuel.	Time required to make Ice-cold water boil, according to the result of the Experiment.	
	lbs.	hrs.	min.
Of this Experiment (No. 31.) were as follows, — — —	14.59	3	37
In the Experiments No. 27 and No. 28, they were, at a medium,	12.385	4	20

The difference in the expence of Fuel in these Experiments with these two Boilers is by no means inconsiderable; it amounts to above 14 *per cent.* and would have amounted to more, if more time had been allowed for heating the water in the Experiment with the new Boiler; for it is easy to show—(what indeed was clearly indicated by all the Experiments)—that, in causing liquids to boil, the quantity of Fuel will be less in proportion as the time employed in that process is long; or, which is the same,—as the Fire is smaller: And the saving of Fuel arising from any given prolongation of the process, will be the greater as the fire-place is more perfect, and as the means used for confining the heat are more effectual.

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Though the general reſults of theſe two ſets of Experiments afforded abundant reaſon to conclude that the alterations I had introduced in arranging the new Boiler were real improvements; yet, when I compared the quantity of Fuel conſumed in the Experiments with this new Boiler, with the much ſmaller quantities, in proportion to the quantity of water, which were employed in ſome of my former Experiments with kitchen Boilers, I was for ſome time quite at a loſs to account for this difference. In all my Experiments with Boilers of different ſizes, from the ſmalleſt ſaucepan up to the largeſt kitchen Boilers, I had invariably found that the *larger* the quantity of water was which was heated, the *leſs*, in proportion, was the quantity of Fuel neceſſary to be employed in that proceſs; and ſo entirely had that prejudice taken poſſeſſion of my mind, that when the ſtrongeſt reaſons for doubt preſented themſelves, they were overlooked; and it was not till I had ſearched in vain on every ſide to diſcover ſome other cauſe to which I could attribute the unexpected appearance that embarraſſed me, that I was induced,—I may ſay forced,—to abandon my former opinion, and to be convinced that what I had too haſtily conſidered as a general law, does not in fact obtain but within narrow limits;—that although, in heating *certain quantities* of liquids, there is an advantage in point of the Economy of Fuel in performing the proceſs on a larger ſcale, in preference to a ſmaller one; yet, when the liquid to be heated amounts to a certain quantity,

quantity, this advantage ceases; and if it exceeds that quantity, it is attended with an expence of Fuel proportionally greater than when the quantity is less.

What the size of a Boiler must be, in order that the saving of Fuel may be a *maximum*, I do not pretend to have determined. I think however that there are some reasons for suspecting that it would not be larger than some of the kitchen Boilers used in my Experiments. But I recollect to have promised my Reader, that I would not give him my opinion, without laying before him at the same time the grounds of those opinions.—In the present case they are as follows:

In an Experiment of which I have already given an account (No. 3.), $7\frac{15}{16}$ lbs. of water, at the temperature of 58°, were made to boil in a saucepan fitted up in my best manner, in a closed fireplace; and the wood consumed was 1 lb. This gives for the *precise result* of the Experiment, 6.68 lbs. of ice-cold water made to boil with 1 lb. of the Fuel.

In another Experiment (No. 12.) made with one of the small Boilers belonging to the kitchen of the Military Academy, fitted up on the same principles, 43.63 lbs. of water, at the temperature of 60°, were made to boil with 3 lbs. of wood. This gives 11.93 lbs. of ice-cold water made to boil with 1 lb. of the Fuel.

Again, in the Experiment No. 20, which was made with a larger Boiler belonging to the same

kitchen,

kitchen, and fitted up in the same manner, 187 lbs. of water, (equal to about 28 gallons,) at the temperature of 55°, were made to boil with the combustion of 8 lbs. of fire-wood. This gives 20.10 lbs. of ice-cold water made to boil with 1 lb. of the wood;—and farther than this I have not been able to push the Economy of Fuel.

In the Experiment No. 26. a Boiler was used, which had been constructed with the express view to see how far it was possible to carry the Economy of Fuel in culinary processes; and it was fitted up with the utmost care, and on the most approved principles. As I thought at that time that a large-sized Boiler was essential to the economizing of Fuel, this Boiler was made to contain 106 gallons. In the Experiment in question it actually contained 508 Bavarian pounds of water, (or about 63 gallons,) at the temperature of 48°; and to make this water boil, 24 lbs. of wood were consumed. This gives 19.01 lbs. of ice-cold water made to boil with 1 lb. of Fuel. Hence it appears that the expence of Fuel was greater in this Experiment than in that last-mentioned.

Again, in the Experiment No. 31. when no less than 11,368 lbs. or 1685 gallons, of water were heated and made to boil in the new Brewhouse Boiler; the wood consumed amounted to 650 lbs. which (as the temperature of the water at the beginning of the Experiment was 65¼°) gives for the *precise result* of the Experiment, 14.59 lbs. of ice-cold water made to boil with the heat generated in the combustion of 1 lb. of the Fuel.

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As the relative quantities of Fuel expended in the Experiments are inverſely as the numbers expreſſing the quantities of ice-cold water, which, from the reſult of each Experiment, it appears might have been heated 180 degrees, or made to boil, under the mean preſſure of the atmoſphere at the level of the ſea, with the heat generated in the combuſtion of 1 lb. of the Fuel; it is evident that theſe numbers meaſure very accurately the different degrees to which the Economy of Fuel was carried in the different Experiments. The Economy of Fuel in heating liquids *depending on the quantity of the liquid*, as ſhown by the foregoing Experiments, may therefore be expreſſed ſhortly in the following manner:

	Quantity of water heated in the Experiment, *in Bavarian* lbs.	Degrees to which the Economy of the Fuel was carried.
	lbs.	lbs.
In the Experiment No. 3,	7.93	6.68
No. 12,	43.63	11.93
No. 16,	187	20.10
No. 26,	508	19.01
No. 31,	11.368	14.59

Before I take my leave of this ſubject I would juſt remark, that the cauſe of the appearances obſerved in the Experiments may, I think, be traced to that property of flame from which it has been denominated a non-conductor of heat:—For if the different particles of flame give off their heat only

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to bodies with which they actually come into contact, the quantity of heat given off by it will be,—*not as its volume*, (and consequently not as the quantity of Fuel consumed,) but rather *as its surface*. And as the surface of the flame, when fire-places are similar, is proportionally greater in small than in large fire-places;—the surfaces of similar bodies being as the *squares* of their corresponding sides, while their volumes are as the *cubes* of those sides;—it is evident that, on that account, less heat in proportion to the quantity generated in the combustion of the Fuel ought to be communicated to the Boiler, when the fire-place and Boiler are large, than when the process is carried on upon a smaller scale.

There are, however, several other circumstances to be taken into the account in determining the effects *of size* in the machinery necessary for boiling liquids; and one of them, which has great influence, is the heat absorbed by the masonry of the fire-place. This loss will most undoubtedly be the smaller, as the fire-place is larger; but to determine the exact point when, the saving on the one hand being just counterbalanced by the loss on the other, any augmentation or diminution of size in the machinery would be attended with a positive loss of heat, is not easy to be ascertained. Provided however that proper attention be paid to the *Management of the Fire*, and that as much heat as possible be generated in the combustion of the Fuel —(which may always be done in the largest fire-place

place as well, if not better, than in ſmaller ones); as that part of the heat which goes off in the ſmoke is indubitably loſt, a thermometer placed in the chimney would indicate, with a conſiderable degree of preciſion, the perfections or imperfections of the fire-place.

It is well known that the ſmoke which riſes from the chimnies of the cloſed fire-places of very large Boilers is much hotter than that which eſcapes from ſmaller fire-places; and I am ſurpriſed that this fact, which has long been known to me, ſhould not have led me to ſuſpect that the waſte of Fuel was proportionally greater in theſe large fire-places than in ſmaller ones.

Beſides the Experiments of which I have given an account, ſeveral others were made with the new Brewhouſe Boiler; and, among others, four Experiments were made on four ſucceeding days, in brewing Beer; and it was found that conſiderably leſs Fuel was expended in theſe trials, than was neceſſary in brewing the ſame quantity of beer in the other Brewhouſe, in which I firſt introduced my improvements. But though the alteration of form, diminution of the thickneſs of the metal, &c. which I had introduced in conſtructing the new Boiler, and alſo in the manner of fitting it up, had produced a conſiderable ſaving of Fuel, yet it was not accompanied by a proportional ſaving of time. I had flattered myſelf that by making the Boiler *very thin* and *very ſhallow*, I ſhould bring its contents to boil in *a very ſhort time;* but I did not conſider fider how much time is neceffary for the combuftion of the Fuel *neceffary* for heating fo large a quantity of water; otherwife my expectations on this head would have been lefs fanguine. The quantity of heat generated in any given time being as the quantity of Fuel confumed, it muft depend in a great meafure on the fize of the fire-place; and when it is required to heat a large quantity of water, or of any liquid, in a very fhort time, either the fire-place muft be large, or (what in my opinion would be ftill better) a number of feparate fire-places,—two or three, for inftance,—muft be made under the fame Boiler. The Boiler fhould be made wide and fhallow, in order to admit of a great number of flues, in which the flame and fmoke of the different Fires fhould be made to circulate feparately *under its bottom.*

The combuftion of the Fuel, and confequently the generation and communication of the heat, may in the fame fire-place* be confiderably accelerated by increafing the draught (as it is called) of the Fire; which may be done by increafing the height of the chimney, or by enlarging the canal leading to the chimney, and keeping the damper open, when that paffage is too fmall;—or by fhortening the length of the flues.

The mafter brewer having expreffed a wifh that fome contrivance might be ufed by which the water might be made to boil a little fooner in the new Boiler, I made an alteration in its fire-place which completely anfwered that purpofe.

But

But besides the desire I had to oblige the master brewer, (who only thought how he could contrive to finish as early as possible his day's work,) I had another, and much more important object in view. Having had reason to suspect that flues which go round on the outside of large Boilers do little more than prevent the escape of the heat by their sides,—which, with infinitely less trouble and less expence, may be prevented by other means,—I was desirous of finding out, by a decisive Experiment, the real amount of the advantages gained by those flues; or the saving of Fuel which they produce. And as I was confident that the suppression of the flue which went round the new Boiler would increase the draught of the fire-place, and accelerate the combustion of the Fuel, I concluded that if my opinion was well founded with respect to the smallness of the advantages derived from these *side flues*, the increase of heat arising from the acceleration of the combustion occasioned by the increased draught on closing them up would more than counterbalance the loss of those advantages, and the time employed in heating the water would be found to be actually less than it was before.

The results of the following Experiments show how far my suspicions were founded.

Experiment, No. 32.

The flue round the outside of the new Brewhouse Boiler having been closed up, and two canals (*a* and *b*, Fig. 21.) formed from the end of the two outſide flues of thoſe ſituated *under* the Boiler, by which two canals (which were both furniſhed with dampers) the ſmoke paſſed off from under the Boiler directly into the chimney; the Experiment No. 31. which was made with the ſame Boiler before the outſide flues were cloſed up, was now repeated with the utmoſt care, in order to aſcertain the effects which the cloſing up of thoſe flues would produce. The quantity of water in the Boiler, and its temperature at the beginning of the Experiment, were the ſame;—the wood uſed as Fuel was taken from the ſame parcel, and it was put into the fire-place in the *ſame quantities*, and at the *ſame intervals of time*;—in ſhort, every circumſtance was the ſame in the two Experiments, excepting only the alterations which had been made in the fire-place. As the length of the flues through which the flame and ſmoke were obliged to paſs to get into the chimney had been diminiſhed more than half, (or reduced from 70 to about 30 feet,) the ſtrength of the draught of the fire-place was much increaſed, as was evident not only from the increaſed violence of the combuſtion of the Fuel, which was very apparent, but alſo from another circumſtance, which I think it my duty to mention. Before the flue round the Boiler was cloſed, if too much Fuel was put into the fire-place at once, it not only did not burn with a clear flame, but frequently the ſmoke, and ſometimes the flame, came out of the fire-place door, even when the damper in the chimney was wide open; but after this flue was cloſed up, it was found to be hardly

hardly poſſible to overcharge the fire-place, and the Fuel always burned with the utmoſt vivacity.

I ought to inform my Reader, that though the entrance into the flue which went round the outſide of the Boiler was cloſed, and another and a ſhorter road opened for the flame and ſmoke to paſs off into the chimney, yet the *cavity* of the flue remained; and by means of openings (c. c. c. c. c. c. Fig. 21. Plate V.) about ſix inches ſquare in the brick-work which ſeparated this old road (which was now ſhut up) from the flues *under the Boiler*, the flame was permitted to paſs into this cavity, and to ſpread itſelf round the outſide of the Boiler. This contrivance (which I would recommend for all Boilers) not only prevents the eſcape of the heat out of the Boiler by its ſides, but contributes ſomething towards heating it; and as the openings in the ſides of the flues do not ſenſibly impede the motion of the flame, they can do no harm.

As the two Experiments, the reſults of which I am about to compare, were made with the greateſt care, and as they are on ſeveral accounts uncommonly intereſting, I ſhall place them in a conſpicuous point of view.

A Comparative View of two Experiments made with a new Brewhouſe Boiler.

The time is reckoned from the beginning of the Experiment, and was the ſame in both Experiments.

Quantity of water in the Boiler 11,368 *lbs. Bavarian weight.*

Time from the beginning of the Experiment.		Fuel put into the fire-place.		Heat of the water in the Boiler.	
		Number of billets.	Quantity in weight.	Experiment No. 31, (outſide flue open).	Experiment No. 32, (outſide flue cloſed).
hrs.	min.	No.	lbs.	degrees.	degrees.
—	—	80	100	65½	65½
0	16	40	50	79	82
0	30	40	50	90	94
0	53	40	50	107	110
1	6	40	50	118	122
1	23	40	50	130	135
1	37	40	50	140	147
1	54	40	50	155	160
2	9	40	50	165	171
2	24	40	50	175	182
2	39	40	50	182	191
2	54	40	50	200	—
2	59	—	—	—	boiled
3	7	—	—	boiled	—

Having found by comparing the reſults of theſe two Experiments, that I had loſt nothing in reſpect to the Economy of Fuel, by ſhutting up the outſide flue of my Boiler, I was now deſirous of aſcertaining how much I had gained in point of time, or or how much the increaſed draught of the fire-place, in conſequence of its flues being ſhortened, enabled me to abridge the time employed in cauſing the contents of the Boiler to boil, in caſes in which it ſhould be advantageous to expedite that proceſs at the expence of a ſmall additional quantity of Fuel.

By the following Experiment, in which the combuſtion of the Fuel was made as rapid as poſſible by keeping the fire-place full of wood, and the regiſter in the aſh-pit door and the damper in the chimney conſtantly quite open, may be ſeen how far I ſucceeded in the attainment of that object.

Experiment; No. 33.

The Boiler contained 11,368 lbs. Bavarian weight of water at the temperature of 47°. The Fuel uſed was pine-wood, moderately ſeaſoned, in billets three feet four inches long, and ſplit into ſmall pieces of about 1 lb. each, that it might burn the more rapidly.

This Experiment was made the 29th of November 1796, the barometer ſtanding at 26 inches 8.7 lines Paris meaſure, and Fahrenheit's thermometer at 33°.

Time.		Fuel put into the fire-place.	Temperature of the water in the copper.
hrs.	min.	lbs.	degrees.
2	0	100	47
—	14	100	58
—	34	100	88
—	51	100	100
3	9	100	123
—	25	100	144
—	39	100	151
4	0	100	—
—	10	—	200
—	17	—	boiled
Time employed - 2	17	Wood conſumed - 800	

In the Experiment No. 32, the ſame quantity of water at the temperature of $65\frac{1}{2}°$, was made to boil in 2 hours 59 minutes, with the conſumption of 625 lbs. of the ſame kind of wood. Had the water in this Experiment been as cold as it was in the Experiment No. 33, (namely at the tempera-

ture

ture of 47°,) inſtead of 625 lbs., 705 lbs. of the Fuel would have been neceſſary; and the proceſs, inſtead of laſting 2 hours and 59 minutes, would have laſted 3 hours and 22 minutes.

Hence we may conclude, that to abridge 1 hour and 5 minutes of 3 hours and 22 minutes in the proceſs of boiling 11,368 lbs. of water, this cannot be done at a leſs additional expence of Fuel than that of 95 lbs. of pine-wood;—or, to abridge the time *one-third*, there muſt be an additional expence of about *one-eighth* more Fuel.

In ſome caſes it will be moſt profitable to ſave time, in others to economiſe Fuel;—and it will always be deſirable to be able to do either, as circumſtances may render moſt expedient.

From a compariſon of the quantities of Fuel conſumed, and conſequently of heat generated, in the ſame time, with the quantities of heat actually communicated to the water, in the Experiments No. 32 and No. 33, during this time, an idea may be formed of the great quantity of heat that may remain in flame and ſmoke after they have paſſed many feet in flues under the thin bottom of a Boiler containing cold water; and this ſhows with how much difficulty theſe hot vapours part with their heat, and how important it is to be acquainted with that fact in order to take meaſures with certainty for economiſing Fuel.

I have been the more particular in my account of theſe Experiments with large Boilers, as I believe no Experiments of the kind on ſo large a ſcale have been yet made; and as they were all conducted with care, their reſults have intrinſic value independent of the particular uſes to which I have applied them.

As in the countries where this Eſſay is likely to be moſt read, pit-coals are more frequently uſed as Fuel than wood, it will not only be ſatisfactory, but in many caſes may be really uſeful to my Reader to know the relative quantities of heat producible from coals and from wood; in order to be able to compare the reſults of Experiments in which coals are uſed as Fuel, with thoſe of which I have here given an account; or to determine the quantity of coals neceſſary in any proceſs which it is known may be performed with a given quantity of wood.

It was my intention to have made a ſet of Experiments on purpoſe to determine the relative quantities of heat producible from all the various kinds of combuſtible bodies which are uſed as Fuel; and I made preparations for beginning them, but I have not yet been able to find leiſure to attend to the ſubject.

The moſt ſatisfactory account I have been able to procure reſpecting the matter in queſtion, is one for which I am indebted to my friend Mr. KIRWAN. By this account, which he tells me is founded on Experiments made by Mr. *Lavoiſier*, it appears, that equal quantities of water, under equal ſurfaces, may be evaporated, and conſequently equal heats produced,

By 403lbs. of Coaks	or in meaſure	By 17 of Coaks
600 — of Pit-coal		10 of Pit-coal
600 — of Charcoal		40 of Charcoal
1089 — of Oak		33 of Oak.

I wiſh

I wiſh I were at liberty to tranſcribe the ingenious and intereſting obſervations which accompanied this eſtimate; but as they make part of a work which I underſtand is preparing for the Preſs, I dare not anticipate what Mr. KIRWAN will himſelf ſoon lay before the Public.

According to this eſtimate it appears that 1089 lbs. of oak produces as much heat in its combuſtion as 600 lbs. of pit-coal. Now, if we ſuppoſe that the pine-wood uſed in my Experiments is capable of producing as much heat *per pound* as oak,—and I have reaſon to think it does not afford leſs,—from the quantity of pine-wood uſed in any of my Experiments, it is eaſy to aſcertain how much coal would have been neceſſary to generate the ſame quantity of heat; for the weight of the coal which would be required is, to the weight of the wood actually conſumed, as 600 to 1089.

In one of my Experiments (No. 31,) —11,368 lbs. of water, at the temperature of $65\frac{1}{2}°$, were made to boil with 650 lbs. of pine-wood. As, when the Experiment was made, the mercury in the barometer ſtood at about 28 Engliſh inches, the temperature of the water when it boiled was only $209\frac{1}{2}°$, conſequently its temperature was raiſed ($209\frac{1}{2}—65\frac{1}{2}$) 144 degrees. Had the water been boiled in London, or in any other place nearly on a level with the ſurface of the ſea, it muſt have been heated to 212° to have been made to boil, conſequently its temperature muſt have been raiſed

 $146\frac{1}{2}°$;

$146\frac{1}{2}°$; and to have done this, inſtead of 650lbs. of wood, $661\frac{1}{2}$ lbs. would have been required; ($140°$ is to 650 lbs. as $146\frac{1}{2}°$ to $661\frac{1}{2}$ lbs.)

If pit-coal were uſed inſtead of wood, $363\frac{1}{2}$ lbs. of that kind of Fuel would have been ſufficient;—for the quantities in weight of different kinds of Fuel required to perform the ſame proceſs being inverſely as the quantities of heat which equal weights of the given kinds of Fuel are capable of generating, or directly as the quantities of the kind of Fuel in queſtion, which are required to produce the ſame heat, it is 1089 to 600, as $661\frac{1}{2}$ lbs. of wood to $363\frac{1}{2}$ lbs. of coal, ſuppoſing the foregoing eſtimate to be exact.

Whether it would be poſſible to cauſe ſo large a quantity of water, (1681 wine gallons,) at the given temperature, ($65\frac{1}{2}°$,) to boil, with this ſmall quantity of coal, I leave to thoſe who are converſant in Experiments of this kind to determine.

From the reſult of my 20th Experiment it appeared that $20\frac{1}{10}$ lbs. of ice-cold water might be heated 180 degrees, or made to boil under the mean preſſure of the atmoſphere at the level of the ſurface of the ocean, with the heat generated in the combuſtion of 1 lb. of pine-wood. Computing from the reſult of this Experiment, and from the relative quantities of heat, producible from pine-wood, and from pit-coal, it appears that the heat generated in the combuſtion of 1 lb. of pit-coal, would make $36\frac{3}{10}$ lbs. of ice-cold water boil.

Hence

Hence it appears that pit-coal ſhould heat 36 times its weight of water, from the freezing point to that of boiling;—and as it has been found by Experiments made with great care by Mr. WATT, that nearly $5\frac{1}{4}$ times as much heat as is ſufficient to heat any given quantity of ice-cold water to the boiling point, is required to reduce that ſame quantity of water, *already boiling-hot*, to ſteam; according to this eſtimation, the heat generated in the combuſtion of 1 lb. of coal ſhould be ſufficient to reduce very nearly 7 lbs. of boiling-hot water to ſteam.

How far theſe eſtimates agree with the Experiments that have been made with ſteam-engines, I know not; but there ſeems to be much reaſon to ſuſpect that the expence of Fuel, in working thoſe engines, is conſiderably greater than it ought to be, or than it would be, were the Boilers and Fire-places conſtructed on the beſt principles, and the Fire properly managed.

In attempts to improve, it is always very deſirable to know exactly what progreſs has been made;—to be able to meaſure the diſtance we have laid behind us in our advances; and alſo that which ſtill remains between us and the object in view. The ground which has been gone over is eaſily meaſured; but to eſtimate that which ſtill lies before us is frequently much more difficult.

The advances I have made in my attempts to improve fire-places, for the purpoſe of economiſing Fuel, may be eſtimated by the reſults of the Experiments

Experiments of which I have given an account in this Eſſay; but it would be ſatisfactory no doubt to know how much farther it is poſſible to puſh the Economy of Fuel.

In my 4th Experiment, $7\frac{15}{16}$ lbs. of water, at the temperature of 58°, were made to boil, at Munich, with 6 lbs. of wood. If, from the reſult of this Experiment, we compute the quantity of ice-cold water which, with the heat generated in the combuſtion of 1 lb. of the Fuel, might be heated 180 degrees, or made to boil, it will turn out to be only $1\frac{1}{7}$ lb. or more exactly 1.11 lb.

According to the reſult of the Experiment No. 20, it appeared, that no leſs than $20\frac{1}{10}$ lbs. of ice-cold water might have been made to boil with the heat generated in the combuſtion of 1 lb. of pine-wood.

It appears, therefore, that about *eighteen times* as much Fuel, in proportion to the quantity of water heated, was expended in the Experiment No. 4, as in that No. 20; and hence we may conclude with the utmoſt certainty, that of the heat generated, or which, with proper management, might have been generated in the combuſtion of the Fuel uſed in the 4th Experiment, leſs than $\frac{1}{18}$ part was employed in heating the water;—the remainder, amounting to more than $\frac{17}{18}$ of the whole quantity, being diſperſed and loſt.

I ventured to give it as my opinion in the beginning of this Eſſay, that "not leſs than *ſeven-eighths* "of the heat generated, or which, with proper ma-"nagement,

" nagement, might be generated from the Fuel ac-
" tually confumed, is carried up into the atmofphere
" with the fmoke, and totally loft."—I will leave it to my Reader to judge whether this opinion was not founded on good and fufficient grounds.

But though it be proved beyond the poffibility of a doubt, that the procefs of heating water was performed in the 20th Experiment with about $\frac{1}{18}$ part of the proportion of Fuel which was actually expended in the 4th Experiment, yet neither of thefe Experiments, nor any deductions that can be founded on their refults, can give us any light with refpect to the *real* lofs of heat, or how much lefs Fuel would be fufficient were there no lofs whatever of heat. The Experiments fhow that the lofs of heat muft have been at leaft *eighteen times* greater in one cafe than in the other; but they do not afford grounds to form even a probable conjecture refpecting the amount of the lofs of heat in the Experiment in which the Economy of Fuel was carried the fartheft, or the poffibility of any farther improvements in the conftruction of fire-places. I fhall, however, by availing myfelf of the labours of others, and comparing the refults of their Experiments with mine, endeavour to throw fome light on this abftrufe fubject.

Doctor CRAWFORD found, by an Experiment contrived with much ingenuity, and which appears to have been executed with the utmoft care, that the heat generated in the combuftion of 30 grains of of charcoal raiſed the temperature of 31 lbs. 7 oz. Troy = 181,920 grains of water, 1$\frac{71}{100}$ degrees of Fahrenheit's thermometer, *when none of the heat generated was ſuffered to eſcape.*

But if 30 grains of charcoal are neceſſary to raiſe the temperature of 181,920 grains of water 1$\frac{71}{100}$ degrees, it would require 3157.9 grains of charcoal to raiſe the temperature of the ſame quantity of water 180 degrees, or from the point of freezing to that of boiling; for it is 1.71° to 30 grains, as 180° to 3157.9 grains. Conſequently the heat generated in the combuſtion of 1 lb. of charcoal would be ſufficient to heat 57.608 lbs. of ice-cold water 180 degrees, or to make it boil;—for 3157.9 grains of charcoal are to 181,920 grains of water as 1 lb. of charcoal to 57.608 lbs. of water.

From the reſults of Mr. Lavoisier's Experiments, it appeared that the quantities of heat generated in the combuſtion of equal weights of charcoal and dry oak, are as 1089 to 600. Hence we may conclude, that equal quantities of heat are generated by 1 lb. of charcoal and 1.815 lbs. of oak; conſequently that the heat generated in the combuſtion of 1.815 lbs. of oak, would heat 57.608 lbs. of ice-cold water,—or 1 lb. of oak, 31.74 lbs. of ice-cold water 180 degrees, or cauſe it to boil;—*were no part of the heat generated in the combuſtion of the Fuel loſt.*

If now we ſuppoſe the quantities of heat producible from equal weights of dry oak and of dry pine-wood to be equal,—(and there is reafon to believe that this fuppofition cannot be far from the truth,)—we can eftimate the real lofs of heat in each of the two Experiments before mentioned, (No. 4 and No. 20,) as alfo in every other cafe in which the quantity of Fuel confumed, and the effects produced by the heat, are known.

Thus, for inftance, in the 20th Experiment, as the effects actually indicated that with *that part* of the heat generated in the combuftion of 1 lb. of the Fuel which *entered the Boiler*, $20\frac{1}{10}$ lbs. of ice-cold water might have been made to boil; as by the above eftimate it appears that $31\frac{74}{100}$ lbs. of ice-cold water might be made to boil with *all* the heat generated in the combuftion of 1 lb. of the Fuel—it is evident that about *one-third* of the heat generated was loft; or $\frac{20.1}{31.74}$ of it was faved.

This lofs is certainly not greater than might reafonably have been expected, efpecially when we confider all the various caufes which confpire in producing it; and I doubt whether the Economy of Fuel will ever be carried much farther.

In the Experiment No. 4, as the effects produced by the heat which entered the Boiler indicated that no more than 1.14 lb. of ice-cold water could have been made to boil with 1 lb. of the Fuel, it appears that in this Experiment only about $\frac{1}{28}$th part of the heat generated was faved.

In all the Experiments made on a very large fcale, with Brewhoufe Boilers, rather more than *one-half* of the heat generated found its way up the chimney, and was loft.

CHAP. VI.

A short Account of a Number of Kitchens, public and private, and Fire-places for various Uses, which have been constructed under the Direction of the Author, in different Places.—Of the Kitchen of the HOUSE *of* INDUSTRY *at* MUNICH—*Of that of the* MILITARY ACADEMY—*Of that of the* MILITARY MESS-HOUSE—*That of the* FARM-HOUSE, *and those belonging to the* INN *in the* ENGLISH GARDEN *at* MUNICH.—*Of the Kitchens of the Hospitals of* LA PIETA *and* LA MISERICORDIA *at* VERONA.—*Of a small Kitchen fitted up as a Model in the House of* SIR JOHN SINCLAIR *Bart. in* LONDON.—*Of the Kitchen of the* FOUNDLING HOSPITAL *in* LONDON.—*Of a* MILITARY KITCHEN *for the Use of* TROOPS *in* CAMP.—*Of a* PORTABLE BOILER *for the Use of* TROOPS *on a* MARCH.—*Of a large* BOILER *fitted up as a Model for* BLEACHERS *at the* LINEN-HALL *in* DUBLIN.—*Of a Fire-place for* COOKING, *and at the same Time* WARMING A LARGE HALL; *and of a* PERPETUAL OVEN, *both fitted up in the* HOUSE *of* INDUSTRY *at* DUBLIN.—*Of the* KITCHEN—LAUNDRY—CHIMNEY FIRE-PLACES—COTTAGE FIRE-PLACE—*and Model*

of

of a LIME-KILN—*fitted up in* IRELAND *in the House of the* DUBLIN SOCIETY.

MY wiſh to give the moſt complete information poſſible with regard to the *grounds* on which the improvements I propoſe are founded, has induced me to be very particular in my account of my Experiments, and of the concluſions and practical inferences I have thought myſelf authoriſed to draw from them; and as theſe inveſtigations have frequently led me into abſtruſe philoſophical diſquiſitions which might not perhaps be very intereſting to many of my readers, to whom a ſimple account of my Fire-places, with directions for conſtructing them, might be really uſeful; in order to accommodate readers of all deſcriptions, I have thought it beſt to divide my ſubject, and to reſerve what I have ſtill to ſay on the mechanical part of it,—the Conſtruction of Kitchen Fire-places,—for a ſeparate Eſſay. In the mean time, for the information of thoſe who may have opportunities of examining any of the Kitchens, or Fire-places, for other purpoſes, which have already been conſtructed on my principles, under my direction, I have annexed the following account of them, and of the particular merits and imperfections of each of them. This account, added to what has been ſaid in the foregoing Chapters of this Eſſay on the conſtruction of Fire-places, will, I flatter myſelf, be found ſufficient to convey the fulleſt information reſpecting the ſubject under conſideration, and enable thoſe,