

ART. XXV.—*On the Combustion of Wet Fuel, in the Furnace of Moses Thompson*; by B. SILLIMAN, Jr., Prof. Gen. and App. Chem. in Yale College.

[Read before the Am. Assoc. for the Adv. of Sci., at Newport, August, 1860.]

IN all ordinary modes of combustion, it is well known that the use of wet fuel is attended with a very great loss of heat, rendered latent in the conversion of water into steam. As the most perfectly air dried wood still contains about 25 per centum of water, according to the experiments of Rumford, the term *wet fuel* might seem appropriate to all fuels, but mineral coal and charcoal. But technically, this term is restricted to substances like peat and those residual products of the arts which, like spent tan, begasse and dye stuffs contain at least one half and often more than half of their weight of water. Until a recent period the attempt to consume these products as sources of heat has been attended with uneconomical results, or total failure. It is the object of this paper to describe a mode of combustion in which by a modification in the form of the furnace the combustion of wet fuel is not only rendered consistent with the best economical results; but which as it involves chemical reactions never before, it is believed, successfully applied for such

purposes, is deserving of particular notice from a scientific as well as from a practical point of view.

It is a well established fact in chemistry, that the affinity of carbon for oxygen, at high temperatures is so strong, that if oxygen is not present in a free state, any compound containing oxygen, which happens to be present is decomposed, in order to satisfy this affinity. This fact is well illustrated in the familiar case of the Blast Furnace where this affinity is employed to deprive the ores of iron of their oxygen in the process of reduction to metallic iron.

In the first stages of combustion, in wet fuels, the chief products given off are steam from the drying of the wet mass, smoke or volatilized carbon and oxyd of carbon, with, of course, a variable proportion of carbonic acid and carburetted hydrogen. These products in all ordinary furnaces, pass on together into the stack, carrying with them the heat which they have absorbed and rendered latent. The problem presented is then to recover the heat thus locked up and lost, and by the furnace now under consideration *this is accomplished by shutting off almost entirely the access of the outer air and causing the wet fuel to supply its own supporter of combustion drawn from the decomposition of the vapor of water at a high temperature by its reaction with free carbon and the oxyd of carbon.*

The practical solution of this problem was first successfully accomplished, as appears from a decision of Patent Commissioner Holt, by the late Moses Thompson, in 1854. The controversial questions growing out of this invention, are entirely foreign to our present purpose and in no way affect its practical or scientific value. Suffice it to say, in passing, that we find in this invention another instance of a truth already so often signalized in the history of inventions, that important results are often obtained, of the highest value in promoting material prosperity and the welfare of society, by those who are guided in their search only by the result in view, and not by any exact knowledge of the scientific principles involved.

Mr. Thompson seems to have been inspired with the conviction that if he could bring the products from the combustion of wet fuel together in a place, hot enough for the purpose, and from which the atmospheric air was excluded, they would, as he expresses it in his patent, mutually "*consume each other.*" This notion was realized, and the reaction secured between the elements of water and the carbon of smoke, or the oxyd of carbon in a part of the furnace called by the inventor, the *mixing chamber*.

Wherever that place may be situated, or however constructed, the one essential thing about it, is, that it should be a very hot place, and one to which the atmospheric air can have no direct access, until it has passed by, and through the burning fuel. It

is in fact a retort or place for combination and reaction, and may be a distinct chamber or flue, or only a recess or enlargement greater or less of the main furnace. Wherever it may be placed, or however built, it must meet the essential conditions of a high temperature, and of atmospheric isolation. In this mixing chamber, then, the important chemical reaction before insisted on, must be set up. The vapor of water is decomposed, furnishing its oxygen to the highly heated carbon to form carbonic acid, while the oxyd of carbon is in like manner exalted to the same condition, and any excess of carbon forms with free hydrogen, marsh gas or light carburetted hydrogen. The vapor of water is thus made to give up not only its constituent elements to form new compounds with oxygen, producing in the change great heat, but a great part of the heat absorbed by the water in becoming steam is also liberated in this change of its physical and chemical condition. Moreover as all these products of combustion and of chemical reaction pass together over the bridge-wall of the furnace into a space from which atmospheric air is not excluded, it then and there happens that any free hydrogen, light carburetted hydrogen or oxyd of carbon which have previously escaped combustion, take fire and burn, yielding up their quota of heat to the general aggregate.

Such is the intensity of heat in that portion of the furnace where these reactions take place that only the most solid structures of refractory fire bricks will endure it, and the color seen throughout that portion of the furnace is of the purest white.

In view of the facts already stated it is easy to understand why it is that when the reactions described are once set up, the admission of a free current of atmospheric air should immediately check the energy of the combustion and soon result in total suspension of the peculiar energy of this furnace. The air containing only one-fifth part of its bulk of oxygen gas, the active agent in combustion, the access of so large a proportion of cold air—four-fifths of which are not only indifferent but positively prejudicial from the quantity of heat it absorbs,—it happens that the temperature of the mixing chamber is rapidly reduced below the point at which carbon can decompose vapor of water and the instant that point is reached the arrival of fresh supplies of steam completes the decline of energy and the furnace commences forthwith to belch forth from its stack dense volumes of smoke and watery vapor. When in proper action not a particle of smoke is visible from the stack of a furnace in which wet fuel is burning, and what is more remarkable the reactions are so evenly balanced that no wreaths of watery vapor are observed, while in the earlier stages of combustion before the proper temperature in the mixing chamber is reached, both these products are seen in great abundance.

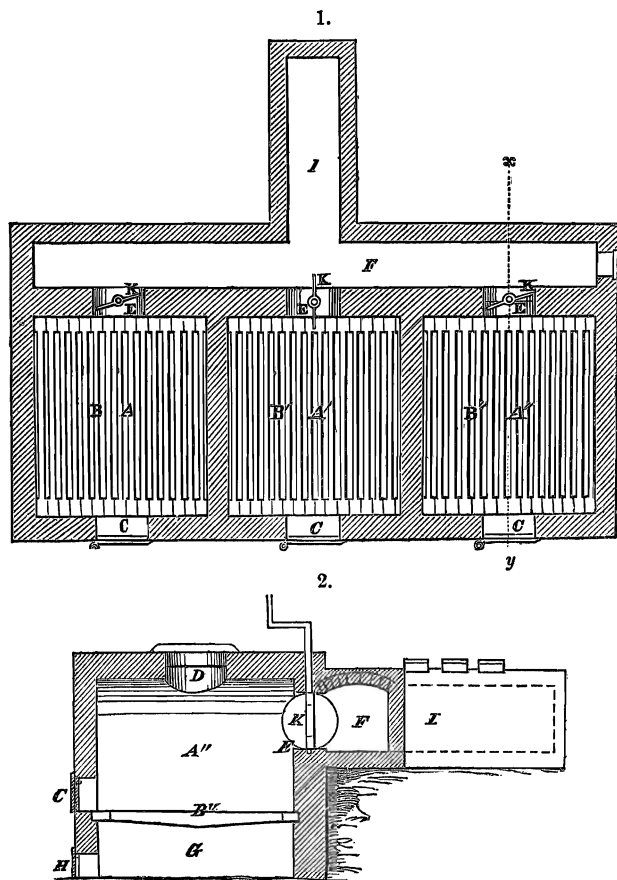
DESCRIPTION OF THE FURNACES.

1st. *Furnace for combustion of wet tan, sawdust, &c.*

Fig. 1, is a horizontal section of a furnace constructed according to the specifications of Thompson's first patent, (issued April 10th, 1855).

Fig. 2, is a vertical section of the same in the line *x y*, of figure 1.

Similar letters indicate corresponding parts in both figures.



The furnace shown in these figures has three square or oblong fire chambers, *A, A', A''*, side by side, experience having shown that not less than three compartments are required to secure the best results in the practical working of the furnace, although in some cases two may suffice, but frequently more than three are

desirable. The fire chambers are furnished with grate bottoms *B, B', B''*, of fire bricks, and are arched at top. Each chamber has a door *C*, in front for lighting and tending the fire. This opening is seldom used after the furnace is once set in action. The wet fuel is supplied through the opening *D* at top. *E* is an opening at the back of each chamber leading to the flue *F*, or the mixing chamber. This opening may be provided with a damper *K* (which must be of fire clay, if of iron the intense heat soon destroys it). Each chamber has a separate ash pit *G* with its opening *H*. This although called an ash pit serves a most important purpose in the economy of the furnace as a receptacle for the burning coals which constantly fall into it from the lower part of the wet mass above, as will be more particularly explained beyond.

If the furnace is used for generating steam the best place for the boiler is over the flue *I*. The inventor remarks in his first patent that the current from the mixing chamber in passing to the place of use, in the case of burning wet tan or other very wet fuel, should descend or pass under a bridge to the place of use equal to about one half of the depth of the burning chamber between the grate and the crown, then rise to the place of use. In case of dry or nearly dry fuel, such as green wood and saw dust, the current should rise immediately after leaving the burning chamber to the place of use.

The mode of conducting the operation of the furnace is as follows: fires being lighted in all the fire chambers with dry fuel and the masonry heated to a high degree, two of the three chambers *A A'* are fed with wet fuel and have their ash pits closed. The other fire chamber is kept in action by dry fuel (its ash pit door being proportionally open) until the process of combustion sets in over the surface of the pile of wet fuel resting on the grates of the other furnaces. As soon as this is the case, wet fuel is added by degrees to the third fire chamber, the ash pit door being at the same time closed. If things have been properly managed so far, the process will now continue by the addition of new portions of wet fuel to each furnace in succession or alternately. The temperature of the mixing chamber *F'* is now seen to be of the most perfect whiteness and not a visible particle of smoke issues from the stack.

Before discussing this process more in detail, let us first consider the Inventor's description of his furnace as designed more particularly for the consumption of *bagasse* or crushed cane stalks.

2. *Furnace for Combustion of Wet Cane Bagasse.*

Fig. 3 is a sectional side view; the interior and exterior form of the furnace, and its several parts according to the specifications of Thompson's patent of Dec. 15, 1857.

3.

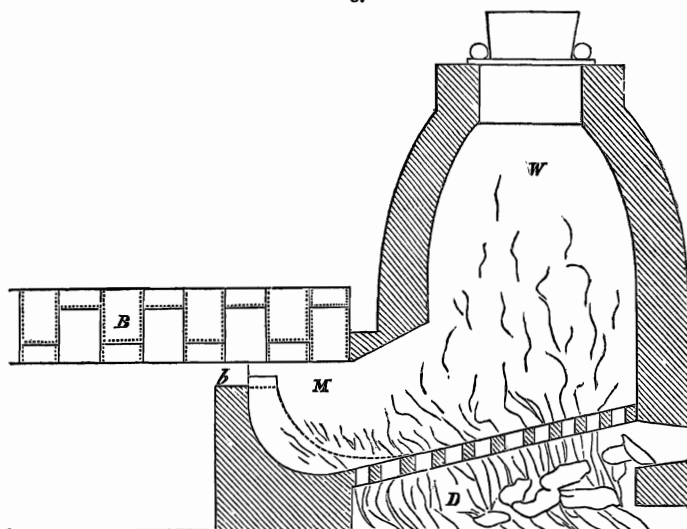


Fig. 4 is a front sectional view of the same, showing the combination of two double furnaces.

4.

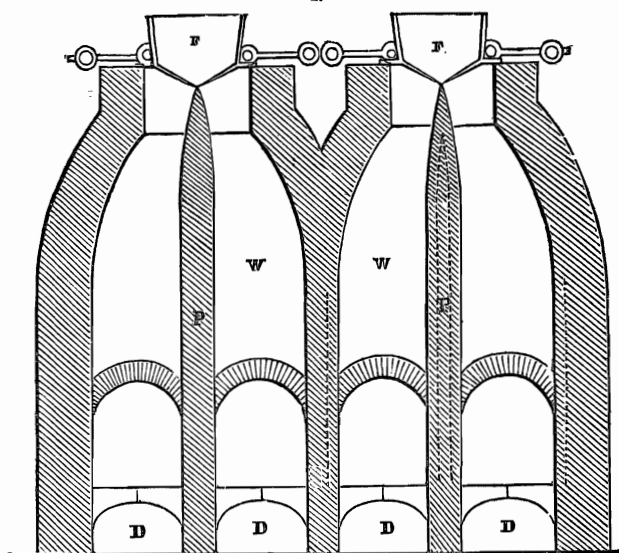
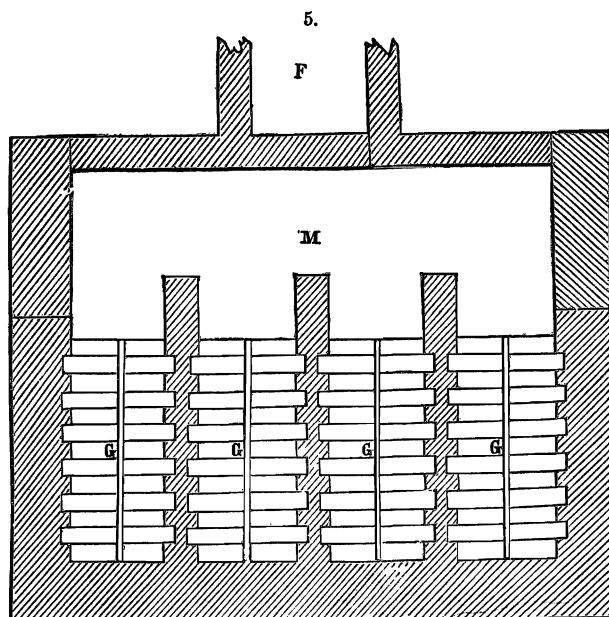


Fig. 5 is a horizontal view of the grate and its relation to the mixing chamber *M* and flue *F*.



Here let the Inventor speak for himself in the language of the patent last named.

"I build two furnaces side by side, each nearly square in its horizontal section. Towards the top I draw in the wall in such manner as to form a kind of dome with a sufficient opening at top to feed the bagasse. The outer walls of these furnaces should be from 24 to 30 inches thick and built with a special view to rendering them non-conducting, the wall near the top, and the partition between the two furnaces may be thinner. In each furnace chamber there should be a partition of fire brick extending across it from front to back and rising nearly to the top, dividing it into two nearly equal parts. The whole interior of the furnace should be of fire brick. The main chamber of each furnace should be divided into two parts—upper and lower—by a fire brick grate about one-fifth the height of the furnace above the hearth, the back end of the grate being a little lower than the front. The bottom of the lower chamber may be a grate with an ash pit, but a hearth is much better.

In each furnace at the front, on each side of the central partition and immediately under the front end of the grate should be doors for feeding wood or other dry fuel, and directly under these doors at the hearth of the lower chamber should be draught openings capable of adjustment to support combustion in the lower chamber.

Extending across the back of both furnaces, and opening into both by flues is a mixing chamber into which all the gases from both furnaces enter in a highly heated state and mix and consume each other on their way to the boiler and stack. This chamber should be about one-half the

capacity of all the fire chambers and it should extend down about as low as the back end of the grate. The flue through which the products of combustion pass out of this chamber and under the boiler should be in section about one square foot to forty cubic feet of mixing chamber.

The feed openings at the top of the furnaces should be closed by doors which open inwards by the weight of the feed, but are self-closing, and do not yield to pressure from within.

The sides of the interior of the upper or wet fuel chamber or drying chamber of the furnace, except the front and back, are corrugated up and down, as also the sides of the central walls or partitions as shown by the dotted lines in Fig. 4, the corrugations extending down to the grate; these corrugations are for the purpose of allowing the heat to radiate upwards from the fire chamber for heating the masonry, and the wet charge, while the gases or vapors driven out of the wet charge by the heat are allowed to descend to the fire chamber or the mixing chamber. If the surfaces of this masonry were smooth the bagasse would lie against them in such a manner as to obstruct the upward radiation of the heat and the downward passage of the vapors.

These corrugations are unnecessary in burning tan and sawdust.

The spaces between the grate bars for burning bagasse should be about 6 inches wide for the finest grinding and twenty inches for the coarsest, and should vary between these widths according to the fineness of grinding, but for sawdust and tan much less, say from one inch to $\frac{3}{4}$ of an inch. The grate should be made of fire brick.

The operation of my furnace is as follows: A hot fire of dry fuel is kindled in the lower or fire chambers of the furnaces and after it has been continued till the masonry is well heated, the chamber above the grate is fed with the bagasse or other wet fuel. This hot fire in the fire chamber, especially towards the front of it under the principal mass of the wet fuel, must be preserved throughout the operation. The heat from the masonry and the fire chamber will be communicated to the wet fuel which will cause steam and other gases to issue from it and mix with the intensely hot gases of combustion from the fire chamber, and in a short time the mixing chamber will present intense combustion and heat, the dampers of the fire chambers being partially closed. The lower part of the wet charge will by degrees become dry and charred and will fall through the grate prepared as above unto the fire chamber and supply or nearly supply the place of other dry fuel in preserving the fire in this chamber and the wet fuel being from time to time supplied will furnish in a highly heated state aqueous vapors which descending through the corrugations and otherwise into the fire chamber and mixing chamber, will be decomposed, furnishing much oxygen to the fire, and supply the oxygen necessary to combustion of all the combustible gases issuing from the fire chamber. If by accident the fire in the lower part of the furnace should predominate, the draught should be diminished and more wet fuel added, and, if by accident, the fire in the fire chamber should become too much cooled down the draught should be let on, and any deficiency of dry fuel should be supplied to the fire chamber. Under proper management little or no dry fuel need be fed to the fire chamber after the operation is fairly commenced, the charred matter falling through the open grate will supply its place; and the caloric thus produced by the combustion of wet

fuel, will be vastly greater than from the same quantity by measure of the same fuel when dry. In the fire chamber and in the mixing chamber under intense heat the carbonaceous gases will decompose the steam from the wet fuel and effect complete combustion.

When the operation is fairly commenced if the water in the wet charge amounts to say fifty per cent by weight of the fuel, the dampers of the fire chamber should be nearly or quite closed to exclude the air; vapor from the wet charge will then descend through the corrugations and otherwise into the fire chambers and support the combustion therein, while other portions of the vapor will enter the mixing chamber and complete the combustion there. If the fuel, however, contains much smaller quantities of water, more air in proportion should be admitted at the damper, the object being to admit no more air than will supply the deficiency of the vapor.

In the drawings, *D* represents the chambers for the dry fuel, *W* those for the wet, *M* the mixing chamber, the dotted line *m* in Fig. 3 limits it for the wettest bagasse, *P* the partition, *F* the feed openings for the wet fuel with their doors, *B* the boiler, *b* the bridge. Little if any of the boiler should extend over the mixing chamber. If any considerable portion of the mixing chamber is covered by the boiler its cooling influence will prevent the decomposition of the the vapor and defeat the object of my invention. Great care should be observed in giving proper dimensions to the mixing chamber, for the perfection of the combustion and the efficiency of the furnace depend greatly upon it. The principal object of this chamber is to give the combustible carbonaceous gases from the fire, and the aqueous gases from the mass of wet fuel an opportunity of mingling together in such a manner and under such circumstances that the aqueous vapor will be decomposed by the carbonaceous gases, and its oxygen given out to complete the combustion of the carbon, without the introduction of air into the mixing chamber, thus saving the caloric previously communicated to the wet charge, while drying it and charring its lower portions, and avoiding the cooling influences of cold air. This can take place effectually only in the presence of a high degree of heat and in the absence of a supply of free oxygen. If this chamber be too small to receive these gases as fast as the furnace is able to produce them the operation will of course be choked and impeded. If the chamber is larger than can be kept densely filled with these gases, of course atmospheric air will be found there at the commencement, and will continue to find its way into the chamber, and while atmospheric air is present, the carbonaceous gases will take their oxygen from that source principally instead of decomposing the steam, and the heat in the chamber will be much diminished and the large quantity of nitrogen $\frac{4}{5}$ contained in the air, which is neither a combustible nor a supporter of combustion, will at once greatly increase the volume of gases to be sent forward to the stack and proportionably decrease its temperature; and when the chamber becomes very large the cooling influences become so great that combustion will immediately cease, and smoke mingled with steam oxygen and nitrogen, will go forward, thus wasting the fuel and imparting only a faint degree of heat to the boiler.

I have therefore fixed the size of the mixing chamber by many careful experiments—and that given above will produce the desired effect with

wet bagasse. For dryer fuels furnishing less vapor, the mixing chamber should be proportionably increased in size to supply the deficiency with air and to effect complete combustion. Rules more precise would be inconsistent with the nature of the subject.

A large and hot fire should always be preserved in the fire chamber below the grate, and directly under the charge of wet fuel, for the purpose of driving the vapor out of it and charring its lower portion—and the grate is left much more open than in furnaces for burning dry fuel of the same size, for the purpose of allowing the charred portions of the wet charge to fall through to supply fuel for this fire as fast as it becomes fit for that purpose, thus consuming the mass with little or no expenditure of other fuel.

What I claim as my improvement in furnaces for burning bagasse and other fuels too wet to be conveniently burned in the usual way and well known ways is :

First, the combination of two chambers, the one above the other, and separated by a grate, the lower one for the combustion of any known dry carbonaceous fuel, and the upper one in immediate proximity therewith to receive heat therefrom for heating and drying the charge of wet fuel, with a mixing chamber, into which both continuously and simultaneously discharge their gases before reaching the thing to be heated, for mingling and mutual combustion.

I also claim in combination with said fire chamber and wet fuel chamber or drying chamber making the grate upon which the wet charge rests sufficiently open to allow the lower portion of the wet charge as it becomes dried and charred to fall through into the fire chamber and keep a hot fire therein, supplying the place of other dry fuel, while the uncharred portions of the wet fuel is properly supported by the grate till dried as described.

I also claim placing the mixing chamber of combustion in substantially the same position described relatively to the fire, and the wet charge, so that the products of combustion from the dry fuel may pass along the lower part of the wet charge, drying and charring it on their way to the mixing chamber, and reach it without being in any considerable degree obstructed or cooled by the wet charge substantially as shown.

I wish it distinctly understood that I make no claim to any of the parts or combination above specified except in their application to the preparation and combustion of wet fuels."

It will be observed that in this mode of combustion the wet fuel is subject to a constant process of distillation by the fire in the ash pit. The products of this distillation react on each other in the mixing chamber in the manner already described, while at the same time a portion of watery vapor is decomposed in the ash pit.

Theoretically no more heat can be generated in this mode of combustion than is consumed in the transformation of water into steam and the conversion of fixed into volatile products. But it is by no means a matter of indifference whether the oxygen requisite for complete combustion is drawn from the atmosphere or is derived from the decomposition of water by carbon

and its oxyd. In the former case, not only is there a great loss of heat carried away by the inefficient nitrogen of the air, but the diluted oxygen can never produce so intense a heat with the carbon as is the result of the reaction of the nascent oxygen with that element. Although Mr. Thompson was no chemist, he did not fail with his natural acumen to perceive this advantage and in his earliest patent he remarks: "After ample experiments I have discovered that any results that can be produced, by the use of dry fuel are inferior (to those obtained from my process) in proportion to the quantity used, and that results like mine can only be obtained by the use of wet fuel * * * fed into an intensely heated chamber: under such circumstances the water in the fuel in presence of the carbonaceous substances in the furnace will be decomposed, giving its oxygen to the carbonaceous matter, dispensing with a draft and its cooling and wasteful influence and rendering the combustion so perfect that no smoke is visible."

Although this mode of combustion of wet fuel is now in use on many sugar plantations in Louisiana, and in some Tanneries of Pennsylvania and New York, no notice of it has so far as I am aware appeared in the scientific Journals. I am not without personal experience of its operation on a large scale, having in 1857 enjoyed the opportunity of studying carefully the management of one of Thompson's furnaces in three compartments (similar to Figs. 1 and 2) built for the combustion of wet peat. That fuel contained over seventy-five per cent of its whole weight of water and was too wet for the best results. But with the use of one-fourth part of dry wood, even this extremely wet and otherwise valueless fuel was rendered efficient, three cords (of 128 cubic feet) of wet peat and one cord of dry wood doing the work of four cords of dry wood in driving a steam boiler.