

nally, that measures the imperfection of the machine as a thermodynamic apparatus.

The ratio of the computed efficiency of the ideal engine to the observed and measured efficiency of the real engine constitutes a gauge of the excellence of the design and of its construction, such as makes this cycle a valuable standard for this special purpose; exactly as the Rankine adiabatic and the Carnot cycle each in its way serves as a special and useful standard. Here, as in the preceding case, the relative efficiency of the real in comparison with the Carnot cycle measures the total imperfection of the machine as a heat-engine; while the relative efficiency of this ideal cycle, as compared with the Carnot, gives a measure of the imperfection of the thermodynamic cycle adopted.

[*To be concluded.*]

CHEMICAL SECTION.

Stated Meeting, held November 17, 1896.

DR. H. F. KELLER, President, in the Chair.

A NEW HIGH-TEMPERATURE FURNACE.

BY H. L. GANTT, A.B., M.E.

Until recently the difficulty of obtaining and controlling extremely high temperatures has kept us to a large measure in ignorance of the uses to which they may be applied. Within the last few years, however, the electrical furnace has thrown a flood of light on this subject, and we to-day realize that high as the temperature of the Siemens steel melting furnace and the blast furnace seems to be, temperatures far higher are destined to be extensively used in the arts at an early date.

Already the electrical furnace has been brought largely into play in the manufacture of aluminum and calcium carbide, and while we realize that electricity is a most efficient and convenient method of obtaining the necessary high temperatures, we must not lose sight of the fact that it is an exceedingly expensive one, and we feel bound to inquire

if even in the Siemens furnace we have exhausted all the possibilities of producing high temperatures by means of combustion. It is the object of this paper to inquire into this subject and to find out the possibilities that may lie in the field of a furnace producing a temperature from $1,000^{\circ}$ to $2,000^{\circ}$ higher than that of the Siemens furnace.

The actions carried on in the electrical furnace, and, in fact, all the actions we propose to study, are of a reducing nature, hence it is necessary that we have an excess of carbon present in our furnace, and, fortunately for our investigation, the highest temperatures obtainable by combustion can be gotten by burning carbon with hot air. Our furnace must then be on the order of a blast furnace, which, while producing a temperature amply high for the purpose of reducing iron from its ore, does not by any means attain the maximum temperature possible by the combustion of carbon.

To try to form some idea of what temperature we may be able to get, we had better consider a coke-fired crucible steel-melting furnace, blown with a cold blast. In such a furnace very soft steel can be melted and made perfectly fluid in about four hours, and that, too, in a pot, the walls of which have but poor heat-conducting power. As the temperature of such steel is about $3,000^{\circ}$ F., it is safe to say that the fire reaches a temperature at least $1,000^{\circ}$ higher, or about $4,000^{\circ}$.

It will be shown later that we can readily heat our air blast to a temperature of $3,000^{\circ}$ F., and we have to ask—what temperature can be obtained with such a blast? If a cold blast will give a temperature of $4,000^{\circ}$ F., a blast heated $3,000^{\circ}$ ought to add just that much to the temperature of the fire, which would then be $7,000^{\circ}$ F. We should not, of course, expect to realize all the benefit from the heat in the blast, but we may safely assume that we shall get two-thirds of it, and that our fire will reach the temperature of $6,000^{\circ}$ F.

With regard to the possibility of obtaining a temperature of $6,000^{\circ}$ F., there will undoubtedly be a difference of opinion; but so far, all our calculations have been based upon the assumption that the combustion takes place under a comparatively low pressure, but we may build our furnace

in such a manner as to admit of our maintaining in it a pressure of one or more atmospheres, in which case the temperatures will be much higher, and in the furnace about to be described, the writer believes there will be no difficulty in obtaining a temperature of at least 6,000° F.

The furnace in question resembles the blast furnace, inasmuch as it is a shaft furnace fired with coke and blown through tuyeres, but differs from the blast furnace in the use of regenerators instead of hot-blast stoves. At the same time the regenerators are something more than is ordinarily included under that term, for in these chambers we complete the combustion of the blast furnace gases, in which respect they resemble somewhat hot-blast stoves. This, however, is as far as the resemblance goes, for the air used to complete this combustion in the regenerators is hot air, while in hot-blast stoves it is cold.

To obtain the conditions above enumerated, we build a Siemens regenerative furnace, which has for the combustion chamber a shaft to hold the fuel and charge and one set of regenerators. If we now connect these regenerators with each other by means of one or more passages near the top, the hot air will be divided into two portions, one of which will pass through the furnace, promoting combustion therein, and the other will pass directly to the outgoing regenerator and complete in there the combustion of the carbonic oxide in the gas to carbonic acid.

In the cuts herewith, *A* represents the combustion chamber, or furnace proper; *G* and *G'* the tuyeres, or flues through which the air enters and the products of combustion leave the furnace; *C* and *C'* are the regenerator chambers in which the secondary combustion takes place, the hot air for which is supplied through the passage *E*.

D and *D'* are simply additional regenerators, connected respectively with *C* and *C'*, long regenerators of small cross-section being considered more efficient than shorter ones of larger sectional area.

K is a four-way reversing valve, through which the blast enters the furnace, and the products of combustion escape to the stack. The furnace proper is provided with three

hoppers, the center one for the material to be reduced and the other two for coke, which by this means is made to surround the charge entirely and protect it from any oxidizing action.

The temperature which we can obtain in this furnace evidently depends upon the temperature of our blast, which, in turn, depends upon that of the regenerators *C* and *C'*.

In order to consider what temperatures we may expect to get in these chambers, let us suppose the furnace to have a fire in the chamber *A*, but to be otherwise quite cool. If a blast be blown through *K*, *D*, *F*, *C* and *G*, we know we can in a short while get a temperature in *A* of from 3,500° to 4,000° F. The products of combustion escaping into *C'*, at the above temperature, will be further burned by the air passing through *E*, and it is safe to say that the chamber *C'* may be heated to the same temperature as the furnace. If, now, the direction of the blast be reversed, the temperature of the air going into *A* and through *E* will certainly be 2,000° F., and our furnace temperature will rise to perhaps 5,000° F., and the products of combustion, containing a large percentage of carbonic oxide, will reach the chamber *C* at a temperature but little lower. These, mingling with air at 2,000° F., will undergo further combustion, and, if they do not increase in temperature, will at least not cool much, and we may certainly expect to get the chamber *C* up to between 4,000° and 4,500° F. Upon reversing, we shall be able to get the air to a temperature above 3,000° F., which was the temperature we considered necessary to give us 6,000° F. in the furnace. As our furnace approaches 6,000° F. in temperature, our regenerators will probably approach 5,000° F., and there seems to be but little doubt that we shall be able to get a temperature as high as we desire, or at least as high as we can find materials to resist.

Having seen what temperatures we can probably obtain in a coke-fired furnace of the proper form, let us try to find out exactly what goes on in an electric furnace and make a comparison of the two sets of conditions.

The formation of calcium carbide in the electrical furnace by means of lime and coke was discovered by Dr. Borchers

about ten years ago. He seems to have investigated the subject quite carefully, and proved to his satisfaction what has since been demonstrated, that the action is not due to electricity, as such, but to the heat produced by it. A short account of his experiments is given in the *Engineering and Mining Journal* of October 14, 1895. More recently this method of manufacture has been put upon a commercial scale by Mr. T. L. Willson, and calcium carbide is said to be manufactured now in large quantities at Niagara Falls.

With regard to the temperature in the electrical furnace, M. Henri Moissan, *Comptes Rendus*, July-December, 1892, Vol. CXV, p. 1,031, tells us that at $3,000^{\circ}$ C. ($5,432^{\circ}$ F.) carbon reduces oxide of calcium, and that the metal is liberated in abundance and unites with the carbon of the electrodes to form calcium carbide.

The difficulty of measuring or even estimating the extremely high temperatures of the electrical furnace is very great; but it is safe to say that the formation of calcium carbide being an endothermic reaction, the temperature of the furnace does not rise much above the point at which it goes on freely, for any heat over and above the amount necessary to maintain this temperature would undoubtedly go to promote chemical action rather than to cause a further increase of temperature, which is probably not very much above $5,500^{\circ}$ F. These conditions are so nearly identical with those which our coke furnace promises, namely, a temperature of $6,000^{\circ}$ F. and a strongly reducing action, that it would seem that any reaction produced in one furnace would occur in the other.

Further, Mr. Walton Clark, General Superintendent of the United Gas Improvement Company, of Philadelphia, is my authority for the statement that there is produced in the blast furnace a substance which, with the addition of water, will give off acetylene gas.

The railroad leading to Chestnut Hill, a suburb of Philadelphia, where Mr. Clark lives, is ballasted with blast furnace slag, and he has often perceived the odor of acetylene in passing over a piece of newly ballasted road after a rain. Knowing lime to be a constituent of the blast furnace

charge, it is certainly most probable that the carbide in the slag giving off acetylene when dampened is that of calcium. If now we grind together a mixture of lime and coke with a little tar for a bond to prevent waste of the ground-up material, and having dried it, charge it in small lumps through the center hopper of our furnace, we shall have conditions far more favorable for the formation of a carbide than can possibly occur in the blast furnace, and almost identical with those occurring in the electrical furnace.

Again, our furnace offers the most favorable conditions that have yet been contrived for the study of that most interesting of problems, the fixation of atmospheric nitrogen and the manufacture of cyanides. The manufacture of cyanides, and especially potassium cyanide, in small quantities in the blast furnace, has been long known, but the conditions most favorable have not been determined. The amount of work being done on the subject now, which is best illustrated by the number of British patents dealing with cyanides, ferrocyanides and sulphocyanides, published during the past ten years, a table of which is given below, indicates an early solution of the problem. The table is as follows:

1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.
4	5	2	4	4	5	7	12	15	33

At a meeting of the Society of Chemical Industry, January 8, 1896, Mr. James T. Conroy, B.Sc., Ph.D., presented a paper, entitled, "Some Experiments Relating to the Manufacture of Cyanides," which is published in the *Journal of the Society of Chemical Industry*, January 31, 1896, and reviews the work that has been done in this line. I give the following extracts from his paper:

"Professor Clark, in 1837, found the efflorescence occurring near the boshes of the Clyde blast furnaces, worked with hot blast, to consist chiefly of potassium cyanide. A similar phenomenon was found to occur in the Hartz, where the hot blast was used; and in 1843, Redtenbacher found it near the light-hole in the furnaces at Marianzoll, in Styria, where it has been produced in marketable quantities. In 1845, Bunsen and Playfair investigated the subject, and

found the zone of formation was just above the tuyeres. To estimate the quantity formed, they drilled a hole in this portion of the furnace and conducted the issuing gas into water. The analysis of the gas gave:

N	58.05
CO	37.43
H	3.18
CN	1.34

"As a result of his work, Bunsen proposed a special blast furnace for the production of cyanides, in which coke and potash were arranged in alternate layers and heated with a strong blast."

It does not appear, however, that such a furnace was ever built.

Continuing our extracts:

"Riechen then investigated the subject and found, under conditions in which only atmospheric nitrogen was present, that cyanides were formed, and he further showed that the temperature must be sufficiently high to produce metallic potassium and that the nitrogen gas should be previously heated.

"His experiments were confirmed by Delbruk.

"These facts having now been firmly established, many attempts have been made to found a working process upon them, and numberless patents, all very similar to each other, have been taken out, but none have proved commercially successful.

"The essential feature is conducting nitrogen (N), or, in the later processes, ammonia (NH₃), over a heated mixture of coke and potash, but the temperature of the formation of the cyanides is in all cases extremely high, in fact, so high as to kill the process, especially when ammonia is used, since this gas decomposes rapidly at the temperature employed."

As a practical confirmation of the above, the most recent patents on the subject specify an intimate mixture of potash (K₂CO₃) and carbon to be subjected to a high heat in the presence of ammonia or nitrogen, and further state that if nitrogen be used the temperature must be very high.

If through the center hopper of our furnace we drop a mixture of coke and potash, which have been thoroughly ground together with a little tar and then dried and broken into lumps, we can obtain these conditions almost perfectly, and the experiment of making potassium cyanide in this manner seems to be worth making.

The next question is—how are we to build a furnace that will withstand such temperatures? In order to resist the fluxing action of lime, the furnace must be lined with a basic material, and, luckily, the most refractory substance available is magnesite, which is basic. What temperature magnesite will stand when subjected to no fluxing action, we do not know, but we do know that it is much more refractory than lime. Again, in the hottest portion of the furnace the exposed surfaces of the magnesite brick will, undoubtedly, become covered with a coat of magnesium carbide, which will probably protect them somewhat. All things considered, it seems quite possible to get a lining to resist the temperature needed.

There are numerous other uses to which this furnace may be put, which are much less problematical than those just discussed, but as they lie in an entirely different line, they are foreign to the subject of this paper.

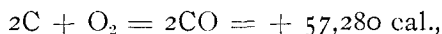
DISCUSSION.

DR. JOS. W. RICHARDS (Correspondence):—Mr. Gantt's proposed furnace is based on sound metallurgical principles. He would not, however, theoretically attain to the temperatures mentioned in his paper. The obtaining of refractory material to withstand temperatures between $2,000^{\circ}$ and $3,000^{\circ}$ C. is, furthermore, not so easy. Moissan has found in the electric furnace that at $2,300^{\circ}$ – $2,400^{\circ}$ C. pure alumina melts to a limpid liquid; at $2,600^{\circ}$, magnesia becomes fluid; at $2,800^{\circ}$ – $3,000^{\circ}$, lime melts, especially in presence of carbon. The only remedy I can propose for this melting of the lining is a water-jacketed furnace, or, at least, water-jacketed around the zone of greatest heat, and then lined with magnesia. The rate of loss of heat would necessarily.

be greater than with pure magnesia walls; but the melting would be checked within a certain distance of the water-jacket, and the lining thenceforth consist of chilled magnesia.

Regarding the theoretically attainable temperature—leaving conduction of heat out of the question, and considering merely the highest temperature momentarily attainable at the instant of combustion—I have made the following calculations:

Let the reaction be:



and the heat set free, calculated to 0° C. , taken as 2,387 calories per kilo of carbon, based on Berthelot and Thomsen's best results. We must first calculate the heat of this combination at high temperatures (represented by t) in order to get the true quantity of heat developed in the furnace. This calculation is based on the principle of thermo-chemistry, that the heat of combustion at any temperature equals the heat of combustion at 0° , *plus* the heat capacity of the fuel and oxygen to that temperature, *minus* the heat capacity of the oxidized product from that temperature to 0° .

For these calculations we have the following data:

Heat in 1 kilo carbon at $t^\circ = 0.53t - 134.6$ calories.

(For t over $1,000^\circ \text{ C.}$ calculated from Weber's results.)

Heat in 1 kilo oxygen at $t^\circ = 0.131875t + 0.00005t^2$.

Heat in 1 kilo carbonic oxide $= 0.1507t + 0.000057t^2$.

(For t between $1,600^\circ$ and $4,000^\circ \text{ C.}$ —Vielle and Berthelot.)

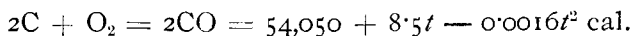
We therefore have:

Heat capacity of C_2 (24 kilos) $= 12.72t - 3,230 \text{ cal.}$

Heat capacity of O_2 (32 kilos) $= 4.22t + 0.0016t^2 \text{ cal.}$

Heat capacity of $2CO$ (56 kilos) $= 8.44t + 0.0032t^2 \text{ cal.}$

And, hence, for temperatures between $1,600^\circ$ and $4,000^\circ \text{ C.}$:



However, since the temperature of the air used may vary, it will be more convenient to leave out of the above expression the heat capacity of the oxygen, and thus to obtain an expression for the heat generated at t° by the combustion of carbon by cold air. If we further omit the heat capacity of 2CO , we will have the heat generated in the furnace, inclusive of the heat capacity of the product, down to 0°C. as a base. This expression is

$$2\text{C} + \text{O}_2 = 2\text{CO} = 54,050 + 12.72t.$$

Having now an expression for the heat generated by the combustion with cold air, the next step is to calculate an expression for the heat capacity of the air used, in order that, if it be preheated, its sensible heat may be added to the heat generated by combustion, to obtain the total heat in the furnace.

The heat capacity of 1 kilo N = $0.1507t + 0.00057t^2$.

$\text{O}_2 = 32$ kilos corresponds to $106\frac{2}{3}$ kilos of nitrogen.

Heat capacity of $106\frac{2}{3}$ N = $16.075t + 0.0061t^2$.

Heat capacity of 32 O = $4.22t + 0.0016t^2$.

Heat capacity of air needed = $20.295t + 0.0077t^2$.

The final step is to calculate an expression for the heat capacity of the products of the combustion. These are:

Heat capacity of 2CO (56 kilos) = $8.44t + 0.0032t^2$.

Heat capacity of $[\text{N}]$ ($106\frac{2}{3}$ kilos) = $16.075t + 0.0061t^2$.

Heat capacity of products = $24.515t + 0.0093t^2$.

Gathering these expressions together, we have:

Heat developed by the combustion = $54,050 + 12.72t$.

Sensible heat of hot air = $20.295t + 0.0077t^2$.

Sensible heat of products of combustion = $24.515t + 0.0093t^2$.

Proceeding from these expressions, and making the assumption that the products of combustion contain, as sensible heat, the sum of the sensible heat in the preheated

air and the heat generated by combustion, we have the following deductions:

I. Air for combustion, cold—

$$24.515t + 0.0093t^2 = 54,050 + 12.72t.$$

from which

$$T = 1,860^\circ \text{C.}$$

This result is not very different from what we know can be obtained by charcoal and an air blast, by which platinum (melting-point, $1,775^\circ \text{C.}$) has been melted by Meyer; but it must be remembered that, in a shallow fire, carbon burns partly to CO_2 , but that, in a furnace of any size, such can only be the case within a few inches of the blast nozzle, and that the body of the furnace probably approximates the temperature calculated above.

II. Air preheated to 730°C.

$$\text{Heat in air} = 20.295(730) + 0.0077(730)^2 = 18,918 \text{ cal.}$$

$$\text{Heat developed by combustion} = 54,050 + 12.72t.$$

$$\text{Total heat in furnace} = 72,968 + 12.72t.$$

Whence

$$24.515t + 0.0093t^2 = 72,968 + 12.75t.$$

and

$$T = 2,238^\circ \text{C.}$$

I have chosen this temperature of air, because it is about the average of the hot-blast for a furnace producing grey iron, and on such a furnace LeChatelier has measured the temperature at the level of the tuyeres as $1,930^\circ \text{C.}$ Since the absorption of heat by slag and iron, and by the expansion of the blast, were not considered in the calculation which gave $2,238^\circ$, the agreement may be considered fairly satisfactory.

III. Air preheated to $1,000^\circ$.

$$T = 2,400^\circ \text{C.}$$

IV. Air preheated to $1,500^\circ$.

$$T = 2,735^\circ \text{C.}$$

V. Air preheated to $2,000^{\circ}$.

$$T = 3,095^{\circ} \text{ C.}$$

VI. Air preheated to $2,500^{\circ}$.

$$T = 3,470^{\circ} \text{ C.}$$

VII. Air preheated to T° .

$$T = 9,000^{\circ} \text{ C.}$$

The last result gives the theoretical temperature attainable by Mr. Gantt's process, pushed to its extreme limit, *i. e.*, with the incoming air preheated to the maximum temperature attainable in the furnace. Of course, it has only a theoretic interest, as showing the imaginary maximum. Practically, result V (air at $2,000^{\circ}$ — furnace at $3,000^{\circ}$) gives what, I think, will be the maximum temperature which it will be possible to attain in an actual test, with the use of materials available, and with the minimum of burden on the fuel.

NOTES AND COMMENTS.*

A PROCESS FOR ELECTROLYTIC DESILVERING ARGENTIFEROUS LEAD.

D. Tommasi, in the *Engineering and Mining Journal*, describes the following mode of procedure:

The principle on which this procedure is founded consists in electrolyzing a lead solution, which not merely possesses an extremely weak electric resistance, but does not give rise to lead peroxide (PbO_2), and, in taking the argentiferous alloy itself as anode and cathode, a metallic disc which cannot be attacked by the bath.

Under the action of the current the lead of the anodes enters into solution, and is transferred, in the state of spongy crystals, upon the disc which serves as cathode, while all the silver contained in the lead, being insoluble in the bath, is deposited at the bottom of the vat in a perforated receiver destined for its collection.

The following is the course to be followed for the electrolytic extraction of silver from argentiferous lead:

We melt the lead and then cast it in moulds having the shape and the thickness which are intended for the anodes. This being done, we suspend

* From the Secretary's monthly reports.