The present invention relates to a furnace for industrial use having a device for elevating the pressure of a combustion gas to be fed therein, which, in a part of its combustion zone is provided with a number of projecting jet nozzles being adapted to provide to the upper and lower portions of the said combustion zone high speed jet zones, each at a determined distance from substances to be treated, such as, steel ingot or blooms, wherein a high temperature combustion gas which has been fed from another combustion zone is jetted out from the said nozzles under high speed into the said high speed jet zone whereby a heat transfer is efficiently conducted therein between the said gas streams and the said substances by utilizing the high coefficient of heat transfer occurring on the surface of said substances due to the said high-speed gas streams, characterized in that a device for elevating the pressure of the said combustion gas is provided in the interior of a supply duct into which the said high temperature combustion gas is fed, being extracted from the said other combustion zone, whereby a small amount of high pressure air or low temperature exhaust gas in a flue, which has been exhausted from an industrial furnace, is jetted out into the supply duct by said device with an ejector nozzle under high speed thereby to elevate the pressure of the said high temperature combustion gas.

3 Claims, 3 Drawing Figures
1

FURNACE HAVING A COMBUSTION PRESSURE ELEVATING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention
The subject matter of the present invention relates to a reheating furnace for reheating substances, such as, steel ingot or blooms. The furnace, in a part of its combustion zone is provided with a number of jet nozzles being arranged in the upper or upper and lower portions thereof, each at a distance from the substances to be reheated. A high temperature combustion gas is introduced directly from another combustion zone into the nozzles by means of a pressure elevating apparatus which operates to elevate the pressure of the high temperature combustion gas and also suck the said gas by the use of a jet stream of a low temperature gas.

2. Description of the Prior Art
The conventional reheating furnaces of the prior art are explained as follows.
With respect to the conventional reheating furnace (including a walking beam type furnace), the specific heat consumption thereof is represented by the following equation:

$$Q_s = \frac{Q_n + Q_w + Q_s + Q_k + Qabs}{Q_c}$$

$Q_n$: total heat quantity released in the furnace kcal/h.
$Q_w$: heat quantity released through wall, etc. (loss of heat quantity)
$Q_s$: heat quantity released and radiated through shutter, etc.
$Q_k$: loss of heat quantity due to water cooling skid, etc.
$Qabs$: heat quantity of exhaust gas being thrown away.

In case the capacity of the furnace is D kg/h, then the specific heat consumption $W_s$ of the furnace is represented as follows:

$$W_s = \frac{Q_n}{D} kcal/kg$$

That is, the above is a proportion of the heat quantity required per kg of the steel substance to be treated, on the basis of the total heat quantity.

On the other hand, the necessary quantity of fuel $B_f$ is represented by the following:

$$B_f = \frac{Q_n}{H_u} = \frac{(Q_n + Q_w + Q_s + Q_k)}{H_u \cdot \eta}$$

In the above equation, $\eta$ represents a furnace efficiency and is as follows:

$$\eta = 1 - \frac{V_g \cdot ig}{H_u}$$

In the above, $V_g$ is exhaust gas quantity Nm$^3$/Nm$^3$ fuel of (kg), and $ig$ is an enthalpy of the exhaust gas, kcal/Nm$^3$.

As is understood from the above equations, it is necessary, in order to decrease the specific heat consumption or the fuel quantity, to reduce the heat quantity of exhaust gas which has been exhausted from a reheating furnace. The said value depends upon the furnace to be used, and in general, is about 35-40 percent.

Recently, a technique has often been practiced in this technical field such that substances are heated rapidly by throwing a large quantity of fuel into the reheating zone for the purpose of increasing the capacity of the furnace, and thus the temperature of the exhaust gas has become very high, such as, 1,200°C, which results in an increase of the exhaust gas loss.

In the conventional technical arts, a heat recovery has hitherto been tried by using a recuperator in a flue for the exhaust gas, as a countermeasure for the above defects. However, the maximum temperature is limited depending upon the quality of the materials constituting the recuperator, and thus consideration should be paid to use diluted air for the purpose of protecting the same.

SUMMARY OF THE INVENTION

In the present invention, an efficient utilization of an exhaust gas, which has been exhausted from a reheating furnace, is accomplished by increasing the heat transfer efficiency in the interior of the convection zone of the furnace.

More precisely, the present invention is based upon the application of such phenomenon to a reheating furnace so that a high coefficient of heat transfer may be attained on the surface of a plate to which jet streams are blown off. Thus, the present reheating furnace comprising a plurality of jet nozzles which are provided in the upper and lower portions of its combustion zone (i.e., reheating zone), the materials to be treated being conveyed between the said upper and lower nozzles, whereby a high temperature combustion gas which has been forwarded from another combustion zone is jetted out from the respective nozzles thereby efficiently to carry out the heat transfer between the said substances and the said gas.

Thus, it is a primary object of the present invention to impart a heat energy contained in a high temperature fluid to substances to be treated so as to increase the temperature of the said substances, by jetting out the said high temperature fluid from nozzles onto the substances under high speed and by utilizing the high coefficient of heat transfer on the surface of the said substances occurring due to the said high temperature fluid stream. In the furnace of the present invention, such heat transfer is conducted in a high speed jet zone.

Another object of the present invention is to jet out a low temperature exhaust gas which has been exhausted from a furnace by the use of a blower, into a forwarding duct for a high temperature combustion gas under high speed, for feeding a high temperature combustion gas from another combustion zone to the jet nozzles, thereby to elevate with ease the pressure of the mixed gas consisting of the said low temperature exhaust gas and said high temperature combustion gas from another combustion zone. In the present invention, this device for forwarding the said high-speed low temperature exhaust gas is referred to as a device for elevating the pressure of the said high temperature combustion gas.

DETAILED DESCRIPTION OF THE INVENTION

The merits attained by the use of the present device for elevating the pressure of the high temperature combustion gas which is to be forwarded to the jet zone in the furnace will be explained below.

The substances to be treated may efficiently be heated in the high-speed jet zone by virtue of the efficient heat transfer which may be conducted in said zone between the said substances and the high-speed combustion gas.
and high temperature jet gas streams, and further, the heat quantity of the high-temperature combustion gas may also be utilized efficiently, and as a result, the loss of exhaust gas is externally reduced. Accordingly, a great advantage results therefrom, in terms of reduction of the specific heat consumption of the furnace economies in fuel expenses, etc.

On the contrary, no development has hitherto been made on the blower to blow directly a high temperature fluid for example, at more than 800°C, for the purpose of forwarding high temperature combustion gas into the jet zone, and thus, the use of a suction fan (400°C-500°C) which is provided in a flue has been tried for forwarding the high temperature combustion gas which has been exhausted from another combustion zone, into the said flue through jet nozzles. In such case, however, various problems occur in the uniformity of distribution of the gas in the jet nozzles, the gas seal to be effected between the other combustion zone and the high-speed jet zone, and thus it is inevitable to somewhat decrease the heat transfer effect in such a case, even by the use of the said jet nozzle.

By virtue of the use of the present pressure elevating device, such defects, as mentioned in the above, may advantageously be eliminated. More precisely, it is possible, by the use of the present pressure elevating device, to elevate the pressure of the high temperature combustion gas and to feed the thus pressure-elevated gas into the jet zone of the furnace, which however, has hitherto been considered impossible. According to the present invention using such device, any decrease of the furnace efficiency which has been inevitable in the use of the suction fan does not occur, and thus a greater effect and a sufficient good result may be attained by the provision of the high-speed jet zone in the industrial furnace.

Now, some preferred embodiments of the present invention will be explained with reference to the drawings attached hereto.

FIG. 1 is a sectional view of an industrial furnace which is provided with a high-speed jet zone in its convection zone and a device for elevating the pressure of a high temperature combustion gas by the use of low temperature exhaust gas jet streams for feeding the high temperature combustion gas.

FIG. 2 is a diagram explaining the principle of the device for elevating the pressure of the high temperature combustion gas.

FIG. 3 is a sectional view of a preheating apparatus wherein a high-speed jet zone is independently separated from an industrial furnace body.

More precisely, FIG. 1 is a sectional view of a five-zone continuous heating furnace which is provided with a pressure elevating device of the present invention in its convection zone. This furnace is an extraction type furnace which is provided with a soaking bed at the pusher outlet part and which consists of five combustion zones in all in the upper and the lower portions.

In the said FIG. 1 (a) is a soaking zone, (b) is a heating zone, (c) is a preheating zone, and (d) is a high-speed jet zone which corresponds to the convection zone of the conventional furnace.

Substances (1) to be treated are pushed into the furnace from the side of the high-speed jet zone by means of a pusher and are forwarded to an extrusion outlet part, sliding on the skid pipe (2) which is supported by post pipes (3) and are heated successively. The temperature of each combustion zone varies, depending upon the quality of the substances to be heated, and, in general, in the case of normal steels, (a) is 1,250°C - 1,300°C, and (b) and (c) are 1,300°C-1,350°C, respectively. In each zone, the height thereof is so high as to be able efficiently to absorb radiation heat.

In the case of conventional reheating furnace, the temperature of an exhaust gas at the outlet of the furnace is from 1,000°C to at most 1,200°C, and the furnace efficiency is about 60 percent.

Referring to the said FIG. 1, the present embodiment comprises of refractory materials are provided in the upper and lower portions of the high-speed jet zone (d), each with a determined distance from the substances to be treated. The disposition of the nozzles may freely be selected in both of the upper and the lower sides, depending upon the temperature distribution state of the substances to be treated, in the form of a zigzag arrangement or any other optional arrangement, with a determined interval between the respective nozzles. With respect to the fixing angle thereof, it is possible to fix the nozzles in the vertical direction to the substances to be treated or with a certain inclined angle to the said substances. With respect to the shape of the nozzles, any optional one may be selected depending upon the use, say with a cut section of a circular shape, an elliptical shape, a rectangular shape, etc.

The high-speed jet zone consists of a casing having its interior side a lining of a refractory body or an insulation body, and through the casing is pierced the nozzles into the interior of the zone. The height of the zone is kept high enough sufficiently to feed the combustion gas which has been jetted out from the said nozzles to the outlet, passing through the upper and the lower portions in the zone without interfering with the effect of the jetstreams. The nozzles are connected to a combustion gas duct 5 which is supported by a large size ceiling beam.

The combustion gas duct 5 is connected, via a header, to a duct 6 for a high temperature combustion gas which has been extracted from another combustion zone of the furnace, such as, in this case, from the middle part between the heating zone and the preheating zone. In the interior of the duct 6 with a lining of a refractory body 7 is installed an ejector nozzle 8, and the other end of the said nozzle 8 is connected to a blower 9 via a butterfly 10. The other outlet of the blower 9 is connected via a partition valve 11 to a branch duct 12 which leads to a low temperature fluid to a jet film nozzle 13 to form a jet film for gas sealing between the preheating zone (c) and the high-speed jet zone (d). The inlet of the blower 9 is inserted into a flue (e) wherein a low temperature exhaust gas in the flue is sucked into the blower.

The pressure in the interior of the furnace is controlled by means of a controlling damper 14 which is provided in front of the combustion gas pressure elevating device.

For the purpose of efficiently operating the present furnace, a supply device for feeding the high temperature combustion gas to the high-speed jet zone is required. A blower has hitherto been used as such supply device for feeding the fluid.

However, in the present case wherein the high temperature combustion gas having a temperature of about
1,300°C is to be fed, any conventional blower cannot be used in view of the quality of the blower body itself which is not resistant to such high temperature.

Under such circumstances, the present invention is based upon the observation that by using an ejector which yields vacuum by the jet stream from the nozzle, the pressure of a large amount of high temperature combustion gas may be elevated by means of a small amount of high pressure air of low temperature exhaust gas. That is, in the present device, the nozzle 8 is inserted into a duct (6) for the high temperature combustion gas, a part of the low temperature exhaust gas in the flue (e) is sucked by means of the blower 9 which is resistant to, for example, a temperature of about 500°C, and the thus sucked gas is jetted out under high speed from the said nozzle 8.

In the present device, a low temperature exhaust gas is used in place of air for the purpose of increasing the efficiency of the device as much as possible.

The FIG. 2 shows the principle of the pressure elevating device of the present invention.

A low temperature exhaust gas, the pressure of which has been elevated to some degree by means of a blower, is jetted out from the nozzle as shown in the said FIG. 2. A high temperature combustion gas is sucked by means of the low temperature exhaust gas streams which are jetted out under high speed at the section taken on line 1-1 of the said FIG. 2. In the section taken on the line 11-11, both gases are mixed, and then the mixed gas is blown out therefrom whereupon the pressure thereof has finally been elevated.

Now, it is supposed that the high temperature combustion gas is flowing in the interior of the duct having an even sectional area F₂ under a speed W₀, and that the static pressure in the duct is P₀ and the absolute temperature therein is T₀. To this, a low temperature exhaust gas having a pressure P₁, and an absolute temperature T₁ is jetted out from a nozzle having a sectional area F₁ under a speed W₁. In this case, the sum of the momentum in the direction of flow and the pressure is same in the every section and thus, the following equation is established wherein g is the acceleration of gravity, R is the gas constant, Cᵢp is the specific heat, A is the heat equivalent of work, and γₑ is the specific gravity of mixed gas:

\[
(F₁ W₁² P₁)/[gRT₁] + F₁ P₁ + [(F₁ - F₀) W₀² P₀]/[gRT₀] + (F₁ - F₀) P₀ = F₂ W₂² P₂/[gRT₂]
\]

From the continuous formula

\[
F₁ W₁ P₁/T₁ + [(F₁ - F₀) W₀ P₀]/[gT₁] = F₂ W₂ P₂/T₂
\]

As an energy equation:

\[
F₁ W₁ P₁/T₁ [(Cᵢp T₁ + A W₀²/2g)] + [(F₁ - F₀) W₀ P₀]/[gT₁] = F₂ W₂ P₂/T₂ [(Cᵢp T₂ + A W₂²/2g)]
\]

Calculating the respective values to satisfy the above three formulae, the speed W₂, the static pressure P₂ and the absolute temperature T₂ at the section taken on the line 11-11 are obtained.

Accordingly, the total pressure after mixing the gases is as follows, the dynamic pressure being yₑ\(W₂²/2g\):

\[
P₂ = P₀ + γₑ (W₂²/2g)
\]

Now, when the furnace efficiency (η) of a reheating furnace having 170T/H is supposed to be 0.8, the combustion gas quantity (V₀) exhausted from the furnace is 77,000 Nm³/h, the temperature (T₀) being 1,350°C. On the other hand, when an exhaust gas having a temperature of about 450°C at the outlet of the furnace is sucked and is jetted out from a nozzle under a pressure of 850 mm Ag and under a jetted speed W₁ = 170 m/s, the jet gas amount V₂ = 1,100 Nm³/h, the temperature (T₂) of the mixed gas being supposed 1,250°C. Solving the above mentioned equation with \(F₂/F₁ = 19\) and \(P₀/P₂ = 1.06\), the speed of the mixed gas (W₂) is 116 m/s, \(P₂ = 10,340 \text{ kg/m}²\). The total pressure is from the above formula (8), as follows:

\[
P₂ = P₀ + γₑ W₂²/[gW₀²] = 10,340 + 158 = 10,498 \text{ kg/m}²
\]

The said pressure corresponds about 160 mm Ag. On the other hand, when the jet speed (WN') from the nozzles in the high-speed jet zone is supposed to be 110 m² and the coefficient of resistance (ξ) 1.0, the pressure loss (Δp) is as follows:

\[
Δp = γₑ (WN²/2g) = 1.0 \times 0.22 \times 110²/19.6 = 136 \text{ mm Ag}
\]

It is understood that a sufficient pressure may be obtained for feeding the said high temperature combustion gas into the high-speed jet nozzle, and jetting out the same therefrom, even if the resistance in the duct is added to the said pressure loss.

Further, the use of the pressure elevating device of the present invention, results in the following merits:

Even when the capacity of the furnace is lowered to the degree of ½ or ⅓ load per total load, if the jetting condition of the pressure elevating device is kept the same as that of the case of the total load, then in the case of ⅓ load, the combustion gas quantity which is fed to the high-speed jet nozzle increases by 40% (\(V₂ = 77,000/3 + 11,000 \text{ Nm}³/h, T₂ = 1,000°C\)). Thus, the jetting speed from the said increment, and as a result, the coefficient of heat transfer is increased and the furnace efficiency is elevated thereby. That is, the above means that the partial load characteristic of the furnace is improved.

In the next place, it is also possible, as another embodiment of the present furnace, to completely separate the high-speed jet zone from the furnace body.

The FIG. 3 shows the embodiment of the said separate construction. That is, the exhaust gas which has been exhausted from a furnace as a high temperature fluid is extracted directly or via a recuperator, and then the substance to be treated, which has been fed into the furnace, is preheated by utilizing the said exhaust gas. In this embodiment, an independent conveyor to convey the substances into the furnace is provided, apart from the furnace body. As to the said conveyor, it is possible to convey the substances by means of a pusher or of a walking beam type conveyor. The substances are exposed to the high-speed and high temperature combustion gas jet streams which are jetted out from the jet nozzle (4) provided in both of the upper and the lower portions in the zone to accept the heat energy of the said jet streams, as being conveyed by means of the said conveyor, whereby the temperature of the said substances themselves is elevated and then the substances are extracted. Regarding other attended equipments, they are the same as in the combined case as mentioned above (FIG. 1), and thus the explanation thereof is omitted. The use of such independent apparatus results in various merits, such as an advantageous improvement in furnace efficiency without any drastic re-construction of a conventional furnace, an easy increase of furnace capacity, etc.

The present invention involved the following merits:
A continuous type heating furnace of 170 T/H is exemplified in the following: This furnace is a five-zone type consisting of one soaking zone, and two preheating zones and heating zones, each in the upper and the lower portions, and in addition thereto, one high-speed jet zone according to the present invention. The calculation of the heat quantity thereof is explained as follows:

With respect to the conventional furnace:

\[ Q_N = 3.57 \times 10^8 \text{ Kcal/h} \]

\[ Q_{ws} = 2.8 \times 10^8 \text{ Kcal/h} \]

\[ Q_k = 10.6 \times 10^8 \text{ Kcal/h} \]

\[ \Sigma Q = Q_l = 49.1 \times 10^8 \text{ Kcal/h} \]

Furnace efficiency \( \eta = 0.635 \)

Air temperature 400°C, exhaust gas temperature 1,100°C

Fundamental unit

\[ W_s = (49.1 \times 10^8)/(0.635 \times 170,000) = 456 \text{ kcal/kg} \]

Fuel quantity

\[ B_f = (49.1 \times 10^8)/(9,860 \times 0.635) = 7,900 \text{ kg/h} \]

(Above, the fuel is a C-heavy oil, and \( H_u = 9,860 \text{ kcal/kg} \)).

Applying the high-speed jet zone of the present invention to the above conventional furnace, the following improvement may be attained.

When the temperature of the high temperature gas to be fed into the high-speed jet zone is 1,250°C and the jet speed is 110 m/s, the average coefficient of the heat transfer on the surface of the treated substances is as follows:

\[ \gamma = 130 \text{ kcal/m}^2\text{h}^\circ \text{C} \]

In this case, when the average temperature difference (\( \Delta t_m \)) is 750°C and the heat transfer area is 235 m² (equal to the upper and lower surfaces), the heat quantity absorbed by the substances in the jet zone is as follows (total loss of water cooling loss, etc. : \( Q'' = 5.1 \times 10^8 \text{ kcal/h} \)):

\[ Q_g = A \Delta t_m + Q'' = 23.0 \times 10^4 + 5.1 \times 10^8 = 28.1 \times 10^8 \text{ kcal/h} \]

The necessary heat quantity (\( Q_h \)) is the soaking zone and the heating zone is calculated by \( Q_2 = Q_j \).

\[ Q_h = (49.1 - 28.1) \times 10^8 = 21.0 \times 10^8 \text{ kcal/h} \]

The exhaust gas temperature is 1,350°C as mentioned above, and so the furnace efficiency (\( \eta \)) at this point is 0.345. Thus, the necessary fuel quantity (\( B_f \)) in the soaking zone and the heating zone is as follows:

\[ B_f = (21.0 \times 10^8)/(0.860 \times 0.345) = 6,200 \text{ kg/h} \]

Next, the heat quantity involved in the combustion gas in the jet zone is \( (77,000 \times 520 + 11,000 \times 156)/10^8 \)

\[ 41.7 \times 10^8 \text{ Kcal/h}, \text{ and the necessary heat quantity to be used therein is } 28.1 \times 10^8 \text{ Kcal/h, and thus, the temperature of the exhaust gas which has been exhausted after being jetted into the jet zone and being heat-transferred therein with the materials to be treated, corresponds to about 460°C, the enthalpy of the exhaust gas being as follows:} \]

\[ i_g = [41.7 \times 10^8 - 28.1 \times 10^8]/(77,000 + 11,000) = 13.6 \times 10^8/88,000 = 155 \text{ Kcal/Nm}^2 \]

In conclusion, the furnace according to the present invention involves the following merits:

1. Furnace efficiency

\[ \eta = 1 - (12.4 \times 155)/9,860 = 1 - 0.195 = 0.805 \]

Fundamental unit

\[ W_s = 456 \times 0.635/0.805 = 360 \text{ Kcal/Kg} \]

Fuel quantity

\[ B_f = 7,900 \times 0.635/0.805 = 6,200 \text{ kg/hN}m^2/h \]

As shown in the above, the fundamental unit of the surface is reduced to 360 Kcal/Kg from 456 Kcal/Kg (of the conventional furnace), and the fuel quantity is reduced by 1,700 Nm²/h. Thus, the expenses are cut down by about 20% or more.

2. Any burners which have been required in the preheating zone of the conventional furnaces are unnecessary in the present furnace.

3. The exhaust gas temperature is about 460°C, and thus the use of any recuperator is unnecessary.

4. The furnace efficiency is high even under partial load.

What is claimed is:

1. In combination a reheating furnace for industrial use, said furnace comprising: a plurality of longitudinally extending combustion zones receiving in sequence, substances to be treated, one of said zones comprising a plurality of longitudinally spaced jet nozzles facing said substances and set a predetermined distance therefrom, duct means commonly connected to said jet nozzles and fluid connected to another of said combustion zones for bleeding high temperature combustion gas therefrom, and ejector nozzles within said duct means facing downstream from the duct connection to said high temperature combustion zone, pipe means fluid coupling said nozzles with the low temperature exhaust gas from said furnace, and blowers means in said pipe means upstream of said nozzles for increasing the pressure of the low temperature gas stream passing through said pipe whereby, jetting of a relatively small amount of high pressure low temperature gas into said duct means under high speed elevates the pressure of the high temperature combustion gas bled from said another combustion zone to utilize the high coefficient of heat transfer as to the surfaces of the substances due to the high speed gas streams emanating from said plurality of longitudinally spaced jet nozzles.

2. The reheating furnace of claim 1 wherein said high speed jet zone is contiguous to the preheating zones of said furnace.

3. The reheating furnace of claim 1 wherein said high speed jet zone is spaced from the preheating zone of said furnace.

* * * * *