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ISSN 0543-5846
METABK 48(3) 203-207 (2009)
UDC – UDK 669.041:662.9 = 111

APPLICATION OF ROOF RADIANT BURNERS IN LARGE PUSHER-TYPE FURNACES

Received – Prispjelo: 2008-03-18
Accepted – Prihvaćeno: 2008-12-20
Review Paper – Pregledni rad

The paper deals with the application of roof flat-flame burners in the pusher-type steel slab reheating furnaces, after furnace reconstruction and replacement of conventional torch burners, with the objective to increase the efficiency of radiative heat transfer from the refractory roof to the charge. Based on observations and on measurements of the construction and process parameters under operating conditions, the advantages and disadvantages of indirectly oriented radiant heat transfer are analysed in relation to the heat transfer in classically fired furnaces.

Key words: pusher furnace, flat-flame burner, indirect radiant roof heating

Primjena stropnih radijacijskih gorionika u velikim potisnim pećima. U radu je obrađena primjena stropnih plosnato plamenih plamenika, koji su ugrađeni u zagrijevne potisne peći umjesto konvencionalnih bočnih plamenika, u svrhu veće učinkovitosti prijenosa topline zračenjem od vatrostalnog stropa prema ulošku. Na osnovi spoznaja do kojih se došlo promatranjem i mjerenjem konstrukcijskih i procesnih parametara u radnim uvjetima, analizirane su prednosti i nedostatci ovog neizravno orijentiranog načina prijenosa topline zračenjem u odnosu na prijenos topline u pećima zagrijavanim na klasičan način.

Ključne riječi: potisna peć, plosnato plameni plamenik, neizravno stropno zagrijavanje zračenjem

INTRODUCTION

Indirectly oriented radiant heat transfer is found when the heat from fuel combustion is transferred to the charge not only directly from the flame, but through an intermediate generally present in the lining of the furnace refractory roof. The flame, which is commonly non-luminous, is characterized by high temperature and relatively low emissivity corresponding to selective radiation of carbon dioxide and water vapour. The heated metal charge has a continuous absorption spectrum so the heat flow to which it is exposed should possibly have a continuous emission spectrum [1].

Consequently, it is rational to intensify heat transfer to the charge by directing the non-luminous combustion gases along the roof surface so that the peak temperature is as close to the surface as possible. As a result, the temperature of the refractory roof is increased and selective radiation of gases is transformed into continuous radiation of the roof. Such an intensively radiant surface is achieved by means of the roof-mounted flat-flame burners (FFB). The burners are designed to spread the flame over the roof surface and thus to ensure intensive heat transfer from the flame to the roof. The gas flow at the burner tunnel exit has no axial velocity [2]. For lack of flame impact on the charge the FFB-heated furnaces are known as indirect heating furnaces.

The paper is based on practical experience with the implementation of the FFB roof-heating technology and aims at assessing its advantages and disadvantages in comparison with classically fired furnaces.

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HEATING FEATURES OF FLAT-FLAME BURNERS

The use of gas flat-flame burners is considered to be appropriate and advantageous in the following cases:

– if the charge in the reheating furnace has a large flat surface, possibly parallel to the furnace roof,
– if the charge heating temperature is up to above 900 °C.

The first FFB design was patented in 1965 [3]. In the 1970s, the flat-flame burner was developed and implemented into the heating technology as a new type of burner in the USA (Bloom), Germany (Brobu), and in countries like ex-Czechoslovakia (formerly Východoslovenské železiarne Košice (VSŽ-K), now U.S. Steel Košice (USS-K). The burner was designed to spread the flame over the roof surface in a thin layer. As the flow rate of the combustion gases in the direction of the burner axis was negligible, the temperature of the refractory roof increased on account of intensive heat transfer from the flame to the roof. In this way, the refractory roof acted as the chief radiating surface [4].

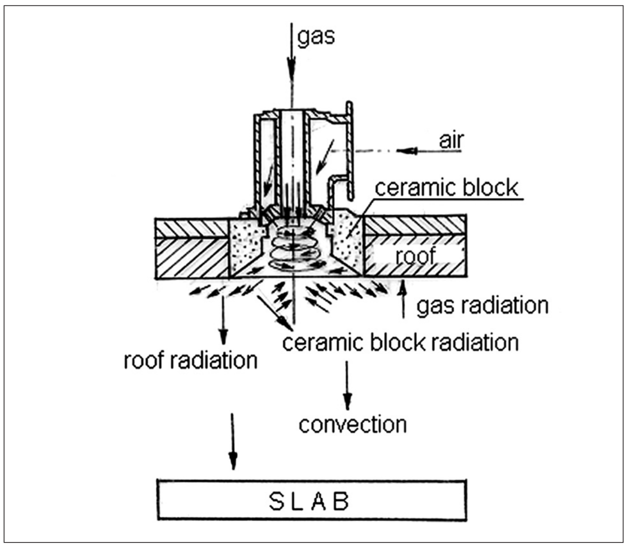

Figure 1. Operation of the flat-flame burner

The construction and functioning of roof burners are presented in Figure 1 showing a roof burner within a ceramic block known as burner quarl [4, 5]. The burner is built into the thermally insulated roof made of refractory material [6, 7]. A gas stream of low velocity is directed into the diffuser channel (tunnel) of the burner quarl serving as a small combustion chamber. An air stream of high velocity, over 100 m/s, is introduced into the gas stream through multiple burner nozzles. There is an angle of 55° between the burner axis and air nozzles. Owing to high air stream velocity and to the angle existing between the fuel stream and the air stream, the mixing rates are fast and the combustible species is oxidised to the combustion product within the space of the burner quarl.

The intensity of radiant heat flow from the roof burner will be affected by the material of which the burner quarl is made. In Dortmund, monitoring of the burner thermal input into a pusher furnace with a 300 t/h output showed the thermal input values in some zones to be lower than those supplied by the furnace producer [4]. The differences between the three zones under observation were as large as 20 per cent. They were caused by improper operation of the inbuilt roof burners with a ceramic quarl which failed to yield the expected heat flux values. On the other hand, with another type of roof burner having a metallic quarl, the expected values were achieved under the nominal thermal input of 0,24 GJ/h. Further development of the ceramic quarl burner therefore became the focus of the investigations. On the basis of empirical results roof burners with a ceramic quarl were used in the pre-heating zones of pusher furnaces at the thermal input values exceeding 0,24 GJ/h.

In USS-K, in the 1974–1995 period, the ceramic quarl burners were used in the pre-heating zone with the thermal input of 8,37 GJ/h, and also in the upper tonnage zone with the thermal input of 3,14 GJ/h.

An important feature of the roof-heating technology is satisfactory temperature control of the individual zones enabling to achieve the necessary furnace output. On the other hand, a major reduction in fuel consumption is achieved if the required decrease in furnace output is within the 100–50 per cent range.

Figure 2 shows the optimisation of specific heat consumption during furnace operation adjusted conformably to the hot rolling mill output. For instance, the heat consumption at the furnace output of 500 t/h was lesser by 8 per cent when three furnaces operated simultaneously than when two were in operation. On the whole, the three furnaces in parallel operation achieved a fuel saving of about 7,5 per cent in comparison with the two operating furnaces. All graphic outputs were made and prepared in terms of [8].

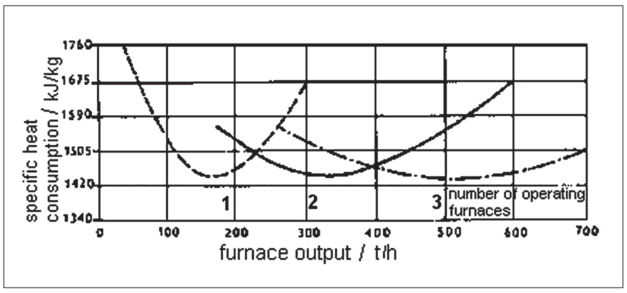

Figure 2. Optimisation of specific heat consumption in respect to furnace output

With the help of the flat-flame burner a higher and more uniform roof temperature can be achieved. The total radiant heat transfer to the charge is enhanced because the proportion of radiation from the roof and from the burner ceramic block is major to gas radiation. This, along with a suitable arrangement of inbuilt burners (a large number of burners of lower thermal power) will increase the furnace thermal efficiency. Proper furnace operation can ensure a significant energy saving especially if performed in conditions of alternating output [4, 9].

With the roof flat-flame burners it is also possible to develop a high-capacity pusher furnace of special construction. Two types of roof burner operating in USS-K are shown in Figure 3. The long and monolithic furnace hearth reduces the temperature differences across the slab section to admissible values.

Experimental investigations of large-scale reheating furnaces carried out under stationary operational conditions confirmed that thermal efficiency could rise by up to 60 per cent if the conventional two-sided heating with torch burners was replaced by one-sided FFB roof heating. In the case of furnace reconstruction, to ensure proper FFB functioning and to achieve optimal thermal efficiency it was also found recommendable, at lesser

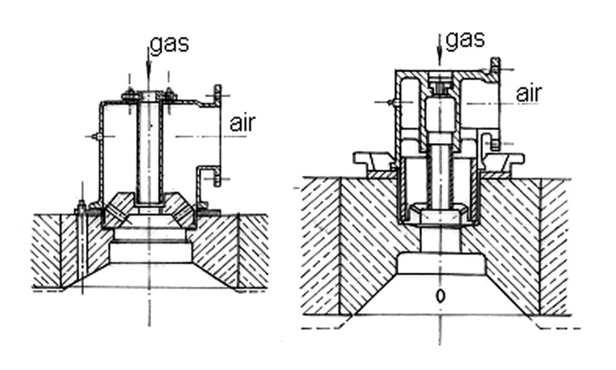

Figure 3. Types of roof flat-flame burner

and medium heat flux values (35–70 kW/m^2), to reduce the distance between the roof and the charge to at least 0,8 m [3]. For comparison, the average value for a furnace with a plane roof and conventional torch burners is 1,5–1,6 m.

In addition to having higher roof temperature, the furnaces with roof flat-flame burners also have a higher heat capacity, i.e. thermal inertia, than the classically fired furnaces. For that reason, at a reduced charge output (under the specific hearth load of 900 kg/(m^2·h), there is a danger of overheating the charge surface. Namely, in the case of a sudden drop in charge output, there occurs an increased radiative heat transfer despite automatic control of the temperature regime.

The advantage of the plane roof, as compared to the traditional inclined roof, lies in a more uniform pressure distribution and also in better automatic control of the furnace heating regime, because the individual heating zones do not affect one another.

ADVANTAGES AND DISADVANTAGES OF ROOF BURNERS

Despite the indisputable advantages of the roof-heated furnaces, there are also a few disadvantages. From the point of view of high energy costs it is often difficult to choose the firing method for a furnace with a high specific hearth load. In the case of long zones with two-sided heating (11–14,3 m), the one-sided roof heating, which lacks a valuable contribution from the lower heating zone, is not efficacious. Experience with a furnace of the total hearth length of 33 m shows that a 6 m long monolithic hearth in the soaking zone is sufficient for eliminating the supercooled parts of the charge known as dark spot, which form in contact with the longitudinal skid pipes in the course of two-sided heating. Likewise, heating at the low roof height cannot ensure a heat flux of 174,450 kW/m^2 in the furnace pre-heating zone. According to furnace experts, an increase in the roof height of up to 3 m might improve heat transfer by 25–30 per cent.

Fast heating rates reduce the time of charge exposure to high temperature so that surface oxidation or the phenomena such as decarburisation and coarse-grain steel structure occur much less frequently. On the other hand, an excessive heating rate at the beginning of the furnace chamber may induce unwanted thermal stresses and structural deformations in the charge.

If the reheating furnace is divided into several zones, control of the heating regime is more effective than with the classically fired furnaces because of a wider regulation range of thermal power insured by flat-flame burners. Besides, the temperature distribution within the furnace chamber and the charge is more uniform. However, it is important to point out that if the number of burners in the pre-heating zone is too small, the zone may be put out of operation.

As a result of reconstruction of the classically fired pusher furnaces and installation of the roof heating in VSŽ-K (USS-K) there were no problems concerning furnace operation for seven years (1974–1981). In the case of one pusher furnace, the originally inbuilt roof made of plastic refractory material preserved 60–70 per cent of its initial volume during the ten years of continuous operation (1974–1984). Based on available references, comparable or even better results have been reported from Germany, USA, Great Britain, and Italy [10].

In the roof-heated furnace pressure control is well manageable provided the furnace chamber profile is free from obstacles. If overpressure is slightly maintained at the discharge end, the pressure at the charge end oscillates around zero.

CONSTRUCTION IMPROVEMENTS

Examples of construction improvement are the reconstruction and upgrading of the pusher furnaces in USS-K between the years 1995 and 2002 following the concept proposed by the Techint company (Italimpianti). The chief goal of the reconstruction and updated furnace automation was reduction of energy consumption, improvement of the slab heating quality, and reduction of material loss through scale formation. The longitudinal profile of the original furnace was retained and the problem of slab discharge was solved by the introduction of a new discharging device.

For heating the charge new flat-flame radiant burners were installed into the roof (Figure 4). To reduce fuel consumption and to achieve a more efficiacious heat transfer the thermal input of the individual zones was redistributed. Owing to the reconstruction and upgrading of the pusher furnaces specific fuel consumption was reduced from 2,3 GJ/t to 1,37–1,52 GJ/t. Scale formation also diminished as a result of lesser air excess due to new burners.

The burner quarl of old construction did not have a smooth inner surface area. It was built in the form of a staircase (Figure 3). The flat-flame burners of contem-

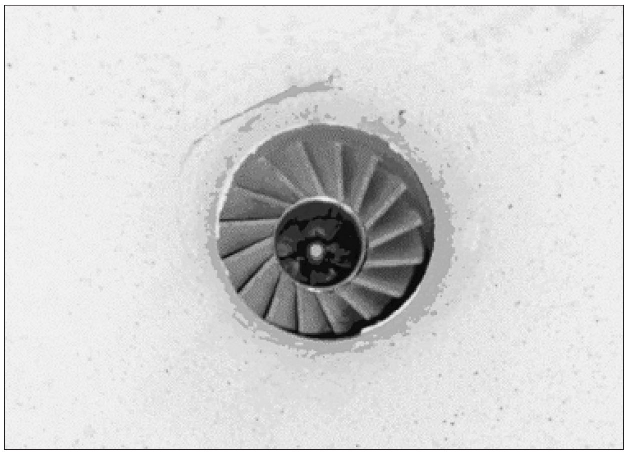

Figure 4. Air swirl-vane arrangement of the flat-flame burner

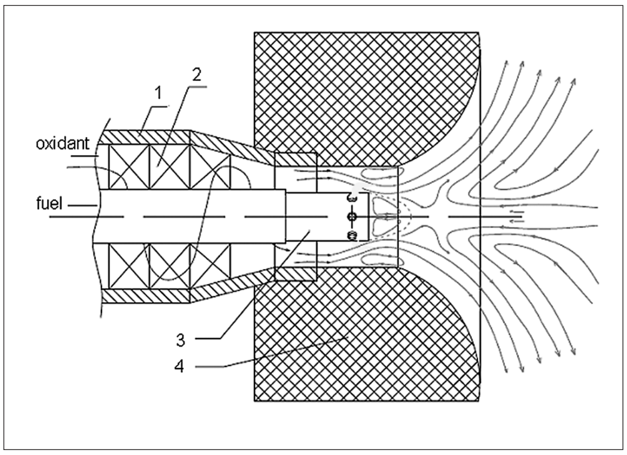

Figure 5. Streamlines in the FFB channel
1 – burner body; 2 – swirler; 3 – gas supplying nozzle assembly; 4 – burner quarl

porary design (Figure 4) are equipped with an air swirl-vane arrangement directed to the gas stream to ensure the best possible mixing of the fuel and the oxidant. Due to the special shape of the quarl, the flame is generally flat. As a result of a relatively large number of burners installed at the furnace roof, a very uniform radiant heat flux is achieved.

Over the past few years a new generation of low-emission (low-NO_x, low-CO) flat-flame burners (LE FFB) has been developed. They are intended for use in industrial furnaces of various types and purpose, beginning with those operating at low temperatures (750–1050 K) to those operating at high temperatures (1500–1900 K) [11–14]. The pollutant concentration values are below those of the international norms and national standards: NO_x – below 20…50 ppm (depending on air preheating temperature (300…800 K) in the furnace temperature range up to 1773 K, and CO – below 10 ppm.

A characteristic feature of the new LE FFB design is the burner quarl having an ultradiffuser channel of toroidal form. Figure 5 shows the layout of the streamlines in the burner tunnel at natural gas combustion under air excess factor $1{,}0 \leq \lambda \leq 1{,}4$ [11]. The burner combustion chamber profile – the FFB channel – is of ultradiffuser form particularly fitting the toroidal quadrant, the latter being tangential to the refractory setting of the furnace. The tunnel is of major importance because it is responsible for the Coanda effect generation, for a 180° flow divergence, and for the adjustment of the flame to the wall (disc-shaped plate profile of the flame). The recirculation ratio and turbulence intensity of the combustion products determine the ignition of the inflammable mixture and burning stability.

CONCLUSIONS

Hundreds of FFB-equipped furnaces have been operating in various industries: in ferrous and non-ferrous metallurgical works, in machine engineering plants, in chemical (including oil refinery) plants, and in building materials (ceramics) factories.

The first pusher furnace with roof-mounted flat-flame burners having a capacity of 300 t/h was installed in the Peine–Salzgitter AG steelworks (Germany) in 1971. In USS-K (VSŽ-K) FFB-equipped pusher furnaces with an output of 205 t/h were introduced between 1974 and 1980. In the 1995–2002 period they underwent further modernisation when roof burners of contemporary construction were introduced.

On the basis of practical experience with the implementation of the FFB roof-heating technology and from comparison with the classically fired furnaces, the following conclusions can be drawn:

- The temperature distribution in the FFB furnace chamber and in the charge is more uniform.
- The faster heating rates, due to FFB, diminish the time of charge exposure to high temperature. Accordingly, the occurrence of surface oxidation or the phenomena like decarburisation and coarse-grain steel structure is greatly reduced.
- A major reduction in fuel consumption of up to almost 40 per cent can be achieved following a 100–50 per cent decrease in furnace output.
- Intensive mixing of gaseous fuel and combustion air ensures fast and complete combustion of the mixture at low excess air value.
- A basic disadvantage of roof heating is the risk of overheating the charge surface following a sudden change in furnace output.

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Note: The responsible translator for English language is prof. Neda Banić