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OPTIMISATION OF DIFFUSION GAS BURNER UTILISATION

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A gas burner is a device which delivers defined amounts of gas fuel and oxidiser to the combustion zone as well as stabilises the flame at its outlet and ensures it has required parameters, i.e. a proper shape and, determined by the heating process, an appropriate level and a balanced distribution of temperatures. Selecting a burner for an existing furnace and designing a new burner for a furnace under development are very complex tasks. Intensification of flame gas dynamics requires high pressure to ensure a high outflow substrate velocity. In the paper, aspects of optimal utilisation of diffusion gas burners are presented. The effects of design and gas-dynamic parameters on burner operation in terms of applied optimisation criteria were analysed. The combustion process was found to influence a change in the air flow characteristics, limiting the potential for achieving the nominal power of the burner with no increased overpressure of the combustion air.
Key words: gas burner, optimisation, flow characteristics.

Optimizacija difuzije upotrebom plinskog gorionika. Plinski gorionik je uređaj koji donosi definirane količine plinskog goriva i sredstva za oksidaciju u zonu izgaranja, stabilizira plamen na svom izlazu i osigurava potrebne parametre, tj. pravilan oblik i, određenu pomoću procesa zagrijavanja, odgovarajuću razinu i uravnoteženu raspodjelu temperature. Odabir gorionika za postojeće peći i konstruiranje novog gorionika za peć u izradi vrlo su složeni zadaci. Pojačavanje dinamike plinskog plamena zahtijeva visok pritisak kako bi se osigurale velike brzine istjecanja supstrata. U radu su prikazani aspekti optimalnog iskorištenja difuzije plinskih gorionika. Analizirani su utjecaji dizajna i plinsko-dinamičkih parametara na rad gorionika u pogledu primijenjenih kriterija optimizacije. Utvrđeno je da proces izgaranja utječe na promjene u karakteristikama strujanja zraka, ograničava potencijal postizanja nominalne snage gorionika bez povećanja tlaka zraka za izgaranje.
Ključne riječi: plinski gorionik, optimizacija, karakterizacija strujanja.

INTRODUCTION

Burners are devices which cause energy conversion and, thus, affect intensity of heat flow in a furnace working chamber. In the industry, a large variety of burner designs can be found. Due to the combustion process stability, it is important whether it occurs in low- and moderate-temperature furnaces, i.e. those meant for heat treatment, or in high-temperature furnaces that are used for charge material heating during plastic working. Diffusion burners demonstrate a higher stability and a relatively lower noise level, which is usually below 82 dB(A), than kinetic and kinetic-diffusion burners. Applied combustion systems should ensure the highest safety of operation as well as required optimal technical and energy parameters consistent with ecological requirements and the anticipated operation period. Selecting a burner for an existing furnace or designing a new burner for implemented, new technologies is a very complex task. To ensure optimal completion of a technological process, specific qualitative energy standards for the flame must be met by applying appropriate selection criteria and algorithms of design of diffusion gas burners [1-4]. The equipment of so-called gas and air paths satisfies the EN-746-2 safety standard and allows for its use in a few burners of a given furnace zone [4].

AREA OF A BURNER OPERATION

In Fig. 1, operational characteristics of a 50 kW diffusion burner for natural gas combustion are presented. The highlighted area corresponds to the recommended range of burner activation [4-8]. In the figure, the areas of safe ignition, optimal utilisation and the burner in furnaces for charge material heating and for heat treatment are marked. When a stable flame is achieved, the volume flow rates of the gas fuel and the air should be fluently increased until the nominal power of the burner is reached. Flame stabilisation is particularly important when the furnace is operated at temperatures lower than the ignition point, during each activation of a cold or chilled furnace and during intensification of the combustion processes.

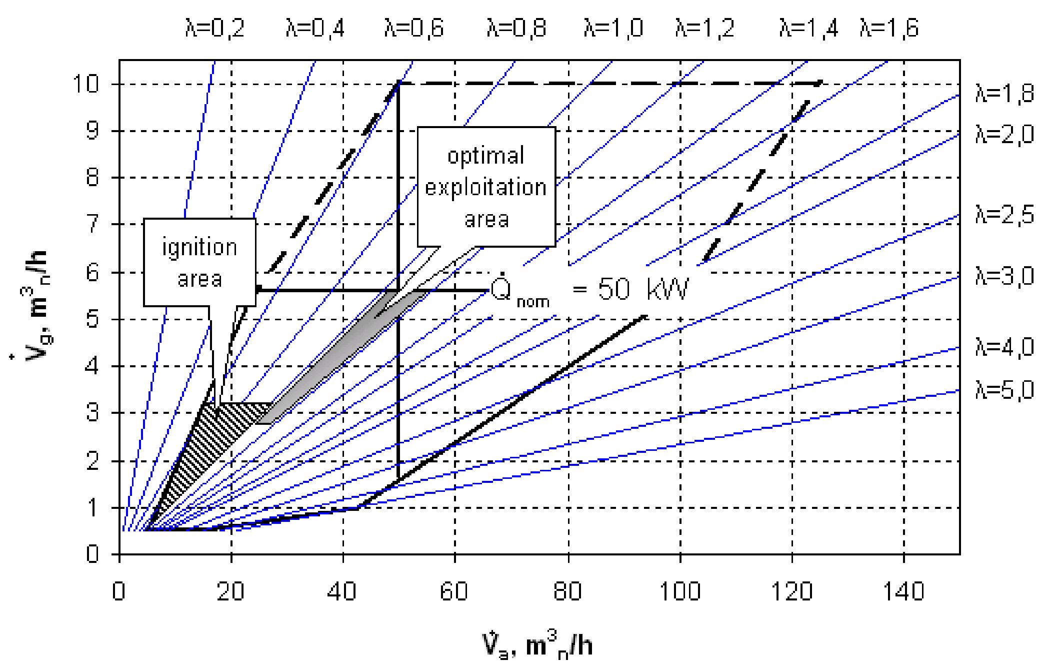

Figure 1. The operational characteristics of a 50 kW burner [8] ($\dot{V}_g$ - gas flow rate, $\dot{V}_a$ - airflow rate, λ - excess air coefficient)

Slika 1. Operativne karakteristike 50 kW gorionika [8] ($\dot{V}_g$ - brzina strujanja plina, $\dot{V}_a$ - brzina strujanja zraka, λ - koeficijent pretička zraka)

The most commonly used stabiliser in heating furnaces is a ceramic burner fitting. A properly matched burner fitting can increase the thermal load of the burner up to 20-fold higher values [9-11]. In Fig. 2, a schematic diagram of a 210 kW cylindrical burner fitting is presented [12]. The main design parameters of fittings include: D/d – a ratio of the fitting outlet diameter (D) to its inlet diameter (d) which is equal to the burner diameter; L/D – a ratio of the cylindrical fitting part length (L) to its outlet diameter (D). In the literature, there is no full agreement with respect to optimal values of fitting parameters, and those recommended by various sources fall within relatively wide ranges [1, 9-11]. For diffusion burners, assumed D/d values are 1.7 to 3.0, while L/D values range from 1.0 to 1.7 [1-9]. The fitting parameters, shown in Fig. 2, are D/d = 1.94, L/D = 1.48 and fall within the recommended ranges.

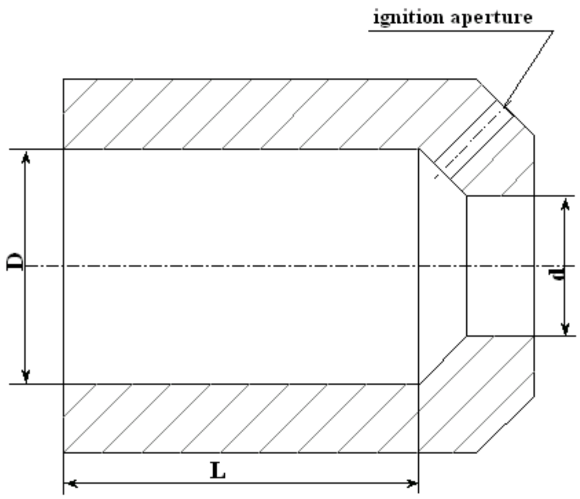

Figure 2. A schematic diagram of a cylindrical burner fitting
Slika 2. Shematski dijagram cilindrične sapnice gorionika

The flame stability also depends on relative pressure (Δp_k) in the combustion chamber. It is assumed that flames of the burners that are meant for operating in furnaces with negative pressure should be stable at the negative pressure higher than the nominal values by 1.2 for $\Delta p_{nom} > -50$ Pa and by 1.5 for $\Delta p_{nom} < -50$ Pa. Burners that operate in chambers with overpressure should be stable at the overpressure higher than the nominal values by 1.2 for $\Delta p_{nom} >$ 50 Pa and by 1.5 for $\Delta p_{nom} <$ 50 Pa. In the case of diffusion burners, too high relative pressures can even prevent activation of the burner.

OPTIMISATION OF A DIFFUSION BURNER OPERATION

Optimisation of diffusion flame parameters mainly depends on the gas dynamics of substrate outflow, the excess air coefficient as well as the air swirl angle and preheat temperature. In heating furnaces, optimisation of the velocities of gas fuel and air outflow from the burner can lead to reduction in gas fuel consumption even by 20%. Optimal values of the air excess coefficient (λ_{opt}) are estimated based on the energy balances of combustion chambers. The resulting models show that the highest average flame temperature for common burners is achieved with λ_{opt} = 1.15, which also corresponds to the maximum thermal efficiency (η_t) of the furnace [13]. A characteristic feature of natural gas combustion is a high air-gas mass ratio, which requires proper selection of the air parameters as their changes have much stronger effects on the flame than gas parameter changes. In the literature, relevant similarity criteria and energy indicators, which allow for optimisation of heat exchange during diffusion combustion of fuels in heating furnaces, are presented. The applied optimisation criteria include: a similarity criterion (K_2) for optimisation of flame parameters in the working chambers, the Froude number (Fr) that expresses the flame stability and the thermal load indicator of the combustion chamber volume ($\dot{q}_v$) [1,10,14].

The similarity criterion K_2: when various gas fuels are applied for furnace heating, the K_2, described in the equation below, is often used for optimisation of the flame parameters:

$$\mathbf{K_2 = \frac{w_0^2}{i_0}}, \tag{1}$$

where: w_0 – substrate outflow velocity, m/s; i_0 – physical and chemical enthalpies of the substrates, J/kg [2, 13]. The K_2 expresses the ratio of kinetic energy to the complete enthalpy of the stream at the burner outlet. It contains data regarding the calorific value of gas fuel, preheating levels of the substrates and the substrate outflow velocities. For the nominal loads of diffusion gas burners, the substrate outflow velocities are usually 30 to 60 m/s. Relatively high differences in the gas fuel and the air outflow velocities are recommended as this promotes their more effective and faster mixing in the combustion chamber.

The Fr number is described as follows:

$$\mathbf{Fr_{a,g} = \frac{w_{a,g}^2}{g \cdot d_{a,g}}}, \tag{2}$$

where: $w_{a,g}$ – average outflow velocities of the air or the gas fuel, m/s; $d_{a,g}$ – a diameter of the air or gas nozzle, m; g – apparent gravity, m/s^2. The recommended Froude number values are: for the airflow: $Fr_a > 85$, and for the gas flow: $Fr_g > 710$. These Fr values, being a function of the substrate outflow gas dynamics, create a straight geometry of the flame and promote equal temperature distribution along its length. Moreover, low NO_x and CO emissions can be achieved during gas fuel combustion in diffusion burners [1, 15, 16-21].

The thermal load of the chamber volume during gas fuel combustion is described by the following equation:

$$\mathbf{\dot{q}_v = \frac{\dot{V}_g \cdot W_{dg}}{V_k}}, \ \mathbf{kW\,m^{-3}} \tag{3}$$

where: $\dot{V}_g$ – volume flow rate of the gas fuel, m^3_n/s; W_{dg} – calorific value of the gas fuel, kJ/m^3_n; V_k – combustion chamber volume, m^3.

In Fig. 3, results of investigations on the air swirl efficiency, i.e. the ratio of the flame physical exergy increase (Δk_b) to the increase in the physical exergies of the substrates (Δk_{bs}) from the blade slope angle (β), are presented. The exergy increases were calculated with respect to a nonswirling flame [13]. For the assumed optimisation criterion – the ratio of exergy increases ($\Delta k_b/\Delta k_{bs}$), the optimal air swirl angle (β), i.e. the blade slope angle, is 20º. This value is consistent with the swirls that are used in practice in long flame burners. In furnaces for heat treatment that operate at temperatures lower than the ignition point, the air swirls of 45º are most commonly used [12].

Such a swirl angle, larger than the optimal value, promotes faster mixing of the combustion substrates as early as within the burner fitting and improves the flame stability. In certain burner types, e.g. North American burners where gas fuel outflow is peripheral and external to the airflow, opposite values of the swirl angles are also used, which may result in a rake angle of 90º. This favours intensified mixing and minimised CO levels in flue gases when $\lambda_{opt} > 1$. With the increase in furnace temperature up to the assumed value for the specific technology, the combustion air temperature rises at a relevant time shift, which results in a higher burner resistance coefficient and a lower value of the excess air coefficient (λ_{rzecz}) in the combustion chamber. During modernisation of the recuperation system with the aim of increasing the air preheat temperature, higher burner resistance values are also to be expected if the burner design has not been modified. To maintain the assumed initial value λ_{rzecz}, settings of the control devices must be altered in order to increase the volume flow rate of delivered air provided that the appropriate margin of the fan parameters is ensured.

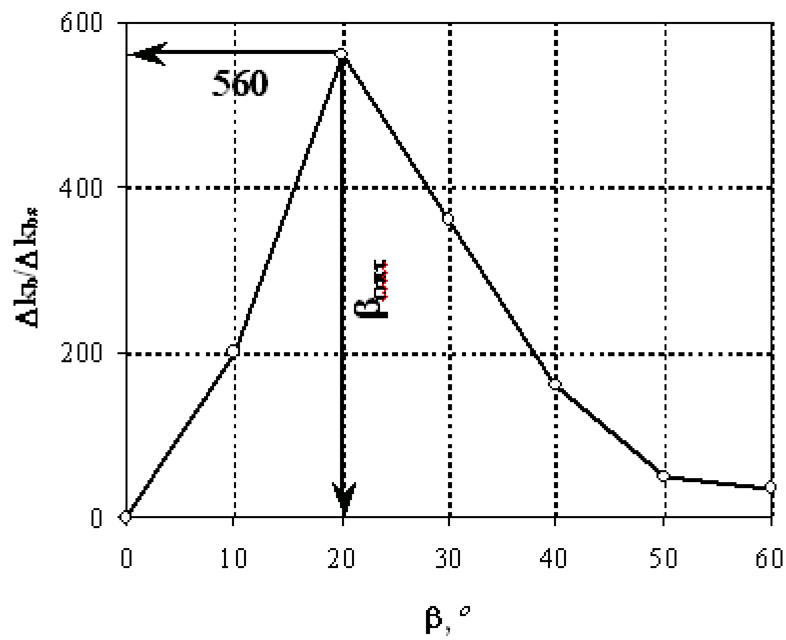

Figure 3. The efficiency of the air swirl [13]
Slika 3. Učinkovitost zračnog vrtloga [13]

CONCLUSION

- The qualitative and quantitative criteria as well as optimisation indicators for the flame, such as Fr_a, K_2 and $\dot{q}_v$, ensure proper combustion control by selecting its parameters within the recommended range of substrate flow characteristics.

- A uniform temperature distribution along the flame length is mainly achieved when appropriate flame stability is ensured, i.e. $Fr_a > 85$, which requires appropriate gas dynamics of the combustion airflow at the burner nozzle outlet.

- The burner should be activated in accordance with control characteristics recommended by the manufacturer within the range of permissible Δp_k changes in the combustion chamber. Proper selection of a flame stabiliser that is most commonly used in heating furnaces, i.e. optimal parameters of the burner fitting within D/d=1.7–3.0 and L/D=1–1.7, markedly increases the area of diffusion burner utilisation. During the furnace operation, particularly at temperatures lower than the gas fuel ignition point, the burners should be fitted with flame control devices.

- The flame stability becomes considerably higher when the swirl of the air and substrates is applied. However, the increase in the air swirl angle and preheat temperature has also a negative effect on increased burner resistance, which results from a higher actual velocity of the air. As a consequence, reduced values of the combustion excess air coefficient below λ_{opt} are observed. This may eventually lead to unplanned incomplete combustion, which is unacceptable in the case of even small overpressures in the combustion chamber due to the CO content in the outflow flue gases. Therefore, while the combustion air is increased during the furnace operation, the excess air coefficient values should be controlled and the λ_{rzecz} should be maintained at the level of λ_{opt}. While the temperature in the furnace space is decreased at the unchanged settings of the air volume flow rate, the increased values of actual excess air coefficient should be adjusted.

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