DIMENSIONING OF THE ORIFICES OF GAS BURNERS FOR INDUSTRIAL FURNACES

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ABSTRACT

It is shown, that the dimensioning of the gas burners in compliance with the fuel-technical and streamline limitations on their work is a complicated problem, demanding the consideration of contradictory and difficult to combine requirements. The non-observance of some of them might not only worsen the exploitation indicators of the whole installation, but also to endanger it with a blast.

The types of gas burners, on which the mentioned restrictions must be imposed when determining the flowing velocities from their orifices, and their cross sections are outlined.

A procedure for dimensioning of the outgoing outlets of these devices is presented. It guarantees the fulfillment of all requirements and ensuring of safe and optimal technical-economical, and ecological by compatible service. For implementation of the presented calculations it is necessary to find a numerical solution of the used equations, for which our own software product is developed.

On the basis of a concrete example the application of the developed algorithm for determination of the optimal diameters the orifices of the considered burner at two different loads is demonstrated. A very good agreement between the corresponding to these flowing out velocities and the recommended in the literature boundaries is achieved. Independently of the illustrative character of the obtained results, the procedure can find wide practical application.

Keywords: gas burners, outlet, velocity of the mixture, limitations, diameter, optimal value.

INTRODUCTION

The burners for gaseous energy bearers have considerable advantages over the remaining fuel burning devices, so they are most widely used in the industrial furnaces [1]. In order to achieve optimal technical-economical and ecological parameters of their function, and also to ensure their safe exploitation, they should be dimensioned in compliance with all limiting conditions, imposed on them from theoretical and practical point of view. The combining of the fuel-technical and the streamline regimes is not always an easy assignment, because contradictory and difficult for compatible implementation requirements are set. That is why the correct determination of their basic dimensions is a serious problem, requiring good knowledge of the technological peculiarities of the corresponding device and of the mechanism of the processes running in it.

The present work sets itself the task, on the basis of an example for difficult concordance of the multidirectional requirements to the dimension of the outgoing outlet of the orifice of a concrete burner, to present a procedure for its determination, which satisfies all streamline limitations of the device, which would guarantee its safe and optimal in technical-economical, and in ecological aspect function.
Types of gas burners, subject to limitations in the determination of the flowing out velocities at the orifices

Our other publication [2] presents the actual classification of the devices for gaseous energy bearers. Some problems in the correct identification of particular constructions and referring them to one or another group are discussed. The trends in the change of the most important regime parameters depending on the place and the mode for implementation of mixing are outlined. From this classification, as well as from data in other literature sources [3-5] is evident, that a sharp borderline between the burners with partial preliminary mixing and those with complete mixing within their cage, schemes of which are displayed in Fig. 1 and Fig. 2 cannot be drawn. Often definitions, based on the received as result of the mixing flame and on the outflow regime of the corresponding fluids (for example laminar partially premixed flame [6]) are employed.

It is seen from the figures, that in the first type of devices, which are even called “burners with an improved mixing” [7, 8], for part of the media the process takes place in the zone in front of the outlet of the tube for feeding the gaseous fuel. The formation of eddies there is supported also by the outflow of the air at an angle j in relation to the longitudinal axis of the burner and the direction of the gas motion. Another part of the two fluxes runs out independently in the working space of the furnace and there the diffusion interaction between them is accomplished.

In the burners with preliminary mixing the process is carried out in the element, named “mixing tube” (position 3 in Fig. 2), located in front of the outlet for supplying with gaseous fuel. Often in the literature these devices are called “injection burners”, but in [2] the groundlessness of such generalization is proved, since other constructions exist (for example ceramic and tunnel burners), which are also with preliminary mixing, but work on the principle of the injector.

An often posed in practice question for the constructors of fuel burning devices, is the determination of the optimal diameters of the orifices for the outgoing gas-air mixture. To the velocity of its outflow are set different and sometimes contradictory requirements. From the formulation of the problem it should follow directly, that it concerns only the burners with preliminary mixing. After a more careful analysis of the burners with partial implementation of the process [2], it is shown, that in many aspects they have a similar behavior. Therefore, it is better the velocity of the mixture (regardless of its homogenization grade) after the separate running out of the gas and the air respectively with velocities \(w_1\), m s\(^{-1}\), and \(w_m\), m s\(^{-1}\), to be put under the same limitations, as for the burners with preliminary mixing. A main reason for this statement is the fact, that due to the use of combinations of different streamline approaches [2] are received constructions, that formally are assigned to the devices with a partial preliminary running of the treated process, but according to the perfection degrees of the diffusion and the combustion, which they can ensure, they approach those with preliminary mixing of the gas and the air. Furthermore, it is difficult to estimate to a what extent the interaction between the media in a given burner with a partial preliminary mixing is implemented in its cage, and to a what extent – out of it. In the case of predominating share of the first process, the device tends to perform like those with (full) preliminary mixing.

Limitations to the flowing out velocities of the orifices

In the previous section it was explained, that actually both burners, shown in Fig. 1 and 2 can be cho-
sen as an example for the presented below devices, if for first of them it is assumed, that the mixing is realized to a great extent in its cage. Since these are very simplified schemes, it should be pointed out, that in practice more often are used devices, in which for implementation of better mixing and/or combustion, and achievement of a torch with a determinate shape, the media run out separately or in a homogenized state through several outlets [2].

In [5] is displayed a flat-flame wall burner in functioning state, which is appropriate as an example for carrying out the presented below considerations and calculations.

Usually when dimensioning a given device the mixture flowing out velocity \( w_m \), m s\(^{-1}\), from its outgoing outlet (orifice) is set [1]. After that by the simple dependence, resulting from the integral form of the continuity equation, at known flow rate of the mixture \( \dot{V}_m \), m\(^3\) s\(^{-1}\), can be found the cross section area of the orifice \( F \), m\(^2\), respectively, if there are more than one \( (n) \) outlets – the cross section area of each of them:

\[
F = \frac{\dot{V}_m}{nw_m}
\]  

(1)

and the diameter of every outlet \( D_i \), m:

\[
D = \sqrt{\frac{4F}{\pi}}
\]  

(2)

The quantities \( w_m \) are determined with the assumption that the fluid is put at normal conditions (temperature 273 K and pressure 1.013x10\(^5\) Pa), and \( \pi = 3.1429 \).

To the flowing out velocity is imposed the following limitation [1]:

\[
w_{\min} > w_m > w_{\max}
\]  

(3)

where \( w_{\min} \), m s\(^{-1}\), is the velocity of jumping (of penetration) of the flame in the cage of the burner, and \( w_{\max} \), m s\(^{-1}\) – this of its tearing from the nozzle of the burner (in the particular case from the outgoing section of the orifice for outflow of the mixture). The first phenomenon would occur at an exceedingly low value of the parameter \( w_m \) and should not be permitted because of an explosion hazard. The second phenomenon leads to interruption of the combustion process, filling of the furnace’s atmosphere with an unburned mixture, and again – a very serious risk of a blast.

In the literature exist different empirical formulas for determination of the two boundary velocities. Sometimes a difficult concordance of the opposite requirements put to them, as well as, by the conformity of the dimension of the outgoing outlet with (1) and (2), is observed.

After analysis and comparison of the proposed correlations, from the point of view of convenience and avoiding containing quantities, the subjective selection of which introduces uncertainty, the presented in [9] dependencies can be recommended:

\[
w_{\min} = 8.65\sqrt{1 + 0.2D^2}
\]  

(4)

and

\[
w_{\max} = 15\sqrt{1 + 0.2D^2}
\]  

(5)

where the diameter \( D \) should be in mm.

**Procedure for dimensioning of the outgoing outlet of the orifice of a concrete burner**

It is naturally to assume, that the best work of a given device would be achieved, if the velocity of the mixture flowing out of it hits the middle of the formed interval for each diameter of the orifice. This velocity \( w_o \), m s\(^{-1}\), is considered an optimal one and it is obviously described by the equation:

\[
w_o = 11.825\sqrt{1 + 0.2D^2}
\]  

(6)

On the other hand, the common solution of (1) and (2) leads to the expression:

\[
w_m = \frac{\dot{V}_m}{\frac{\pi D^2}{n}}
\]  

(7)

The volumetric flow rate of the mixture can be determined as follows [10]:

\[
\dot{V}_m = (1 + L_u)B
\]  

(8)

where \( B \), m\(^3\) s\(^{-1}\), is the fuel consumption, \( L_u \), m\(^3\) m\(^3\) – the volume of the moist air, necessary for the completely
combustion of 1 m³ of gas at the actually fed quantity of air with air ratio α.

Since when designing a given burner more often is known its necessary calorific power \( P \), kW, or is set it is necessary to give an account of the relation:

\[
B = \frac{P}{Q_i}
\]  

in which \( Q_i \), kJ m⁻³, is the lower specific heating value of the gas.

Considering (8) and (9), from (7) is received the final working formula for finding the flowing out velocity:

\[
w_m = \frac{(1 + L_{a}) P}{n \pi D^2} = \frac{4(1 + L_{a}) P}{n \pi D^2 Q_i}
\]  

from which its corresponding value of the diameter of each from the outgoing outlets of the burner, can also be determined.

RESULTS AND DISCUSSION

The velocity the mixture flowing out from the outgoing outlet (outlets) of the burner should satisfy both limitations (6) and (10), i.e. it is necessary to fulfill the condition:

\[ w_m = w_o \]  

The strict analytical finding of the common root of these two equations, and consequently – the optimal value of the diameter of each of the outlets for outflow of the mixture \( D_o \), mm, is not possible. Because of that our own computer program for their numerical solution for a concrete chosen example is developed.

Table 1 presents the assumed input data for performing of this procedure. Two versions are considered – at maximal calorific power 10 kW and at a load of 50% from it, i.e. at \( P = 5 \) kW.

In Fig. 3 and 4 the results from the implemented calculations respectively at capacity of the burner 10 and 5 kW are visualized. They demonstrate that the optimal value of the diameter of the outgoing outlets of the device is receiving graphically as a point of intersection of the curve, showing the dependence of the optimal flowing out velocity according to equation (6), and the curve, describing the relation (10) with the data, presented in Table 1.

For the maximal power of the burner (10 kW) it is obtained, that \( D_o = 2.87 \) mm. At 50% load, i.e. by decrease in half of the flow rate of the mixture, \( D_o = 2.25 \) mm. The corresponding to these values optimal flowing out velocities are, respectively, 18.5 m s⁻¹ and 16.7 m s⁻¹. They satisfy very well the postulated in [9] condition, that for turbulent flow, which is the consid-

<table>
<thead>
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<th>No</th>
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<th>Symbol</th>
<th>Value</th>
<th>Measure</th>
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<tbody>
<tr>
<td>1</td>
<td>Used fuel – methane</td>
<td>CH₄</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>Lower specific heating value of the fuel</td>
<td>( Q_i )</td>
<td>35357</td>
<td>KJ m⁻³</td>
</tr>
<tr>
<td>3</td>
<td>Air ratio</td>
<td>( \alpha )</td>
<td>1.05</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>Volume of the moist air, necessary for the complete combustion of 1 m³ of gas at the actually fed quantity of air with air ratio ( \alpha )</td>
<td>( L_a )</td>
<td>10.012*</td>
<td>m³ m⁻³</td>
</tr>
<tr>
<td>5</td>
<td>Calorific power of the burner</td>
<td>( P )</td>
<td>10 – Fig. 4 5 – Fig. 5</td>
<td>kW</td>
</tr>
<tr>
<td>6</td>
<td>Number of the outlets for outflow of the mixture from the nozzle of the burner</td>
<td>( n )</td>
<td>24</td>
<td>–</td>
</tr>
</tbody>
</table>

* This value is determined by our own software product for calculation of the parameters, characterizing the combustion process.
CONCLUSIONS

On the grounds of an analysis of the work of particular gas burner constructions those types of them, which are subject to limitations in the determination of the velocities in the outgoing sections of their orifices, are pointed out.

A procedure for dimensioning of the outlets, from which the outflow of the gas-air mixture occurs, is suggested and realized in a developed software. It ensures satisfying of all streamline limitations imposed on the device, and in the same time guarantees its safety and its optimal work from technical-economical, as well as in ecological point of view.

On the basis of a concretely chosen burner the use of the proposed algorithm for determination of the optimal diameters of its orifices for two different heat loads is demonstrated. A very good agreement between the corresponding to the chosen values flowing out velocities and the recommended in the literature boundaries is displayed. The possibilities for wide application of the suggested approach are emphasized.

REFERENCES

2. R.D. Stanev, Perfection of Mixing between Gaseous Fuel and Air in Industrial Burners – Technical and


