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MATHEMATICAL MODELING OF TEMPERATURE REGIMES OF BURNERS OF STABILIZING TYPE WITH THERMO-BARRIER COATINGS

The results of CFD simulation of temperature regimes of flat flame stabilizers of microjet burners are presented when thermo-barrier coatings are applied to their outer surface. A comparative analysis of the heat state of the flame stabilizer walls is performed in the presence and absence of these coatings in a wide range of variations of the boiler load (20…100%). It is shown, that at low boiler load the temperature of flame stabilizers with end niches can significantly exceed the permissible level both during the application of protective coatings and in the absence thereof. It is noted that the formation of an unfavorable heat state of stabilizers with coatings is due to the effect of surface development associated with the presence of an end protrusion. The possibility of providing the required temperature regime of the flame stabilizers walls by changing their configuration due to the removal of the end protrusion is considered. It is shown, that this change in the shape of the flame stabilizer allows, under conditions of the presence of a thermo-barrier coating to lower its temperature level to acceptable values. [dx.doi.org/10.29010/083.4]

Keywords: *thermo-barrier coatings; heat state; CFD simulation; burner devices; flame stabilizer.*

Introduction

Burner devices of the stabilizing type have a number of well-known advantages and are widely used in energy practice. The reliability and durability of these devices is largely determined by their heat state during operation. A number of requirements are presented to this state, the main one of which is the requirement to ensure that the elements of the burner devices have temperature levels that do not exceed the prescribed permissible values [1–6].

Among the various ways to organize favourable temperature regimes of stabilizer burners, special attention should be paid to the use of thermo-barrier coatings on the outer surfaces of flame stabilizers [7–9]. This circumstance determines the actuality of the study of the heat state of the burner devices of stabilizing type with such coatings.

The work also carried out studies on the establishment of regularities in the effect on the heat state of the stabilizers of the end protrusion, which serves as the formation of a niche cavity on the end of the stabilizer.

Formulation of the Article Purpose

The purpose of the study is to justify the possibility of using thermo-barrier coatings on the outer surfaces of flame stabilizers to provide the required temperature regimes for burner devices.

Problem Formulation and Methodology of Research

The heat state of the stabilizer burner device, whose scheme is shown in Fig. 1, was investigated. The device is equipped with a special system of so-called self-cooling, in which the role of the coolant plays natural gas, which is subject to further combustion. The burner was integrated into the gas-fired boiler plant. Thermo-barrier coatings were applied to a section of the outer surface of the flame stabilizer; covering the niche cavity proper, the end face of the stabilizer and part of its lateral surface located between them.

Mathematical modeling was used as a method of research. The increasing use of this method as a tool for investigating transport processes in burners of different types is associated with next advantages: the possibility of obtaining information about the local characteristics of the processes under study, the relative simplicity of carrying out wide parametric studies, the relatively low cost, etc. [10–19].

The step-by-step simulation technique was used when implementing the solution of the problem under consideration [20]. The solution is based on the URANS approach using the FLUENT software. Based on the results of the verification of turbulent transfer models, the use of the RNG k-ε turbulence model is justified.

In the course of the research, a comparative analysis of the temperature regimes of flame stabilizers was carried out in the presence and absence of thermo-barrier coatings. This analysis was carried out over a wide range of boiler load changes (20...100%). The necessity to study the regularities of the influence of the boiler load on the temperature levels of the flame stabilizers is because the efficiency of their cooling systems depends significantly on the given load. Indeed, in the cooling system in question, the coolant charge varies in accordance with the boiler load. Consequently, the cooling conditions of the flame stabilizer deteriorate with decreasing the given load. In this regard, when assessing the effectiveness of the use of thermo-barrier coatings and cooling systems of flame stabilizers, spe-

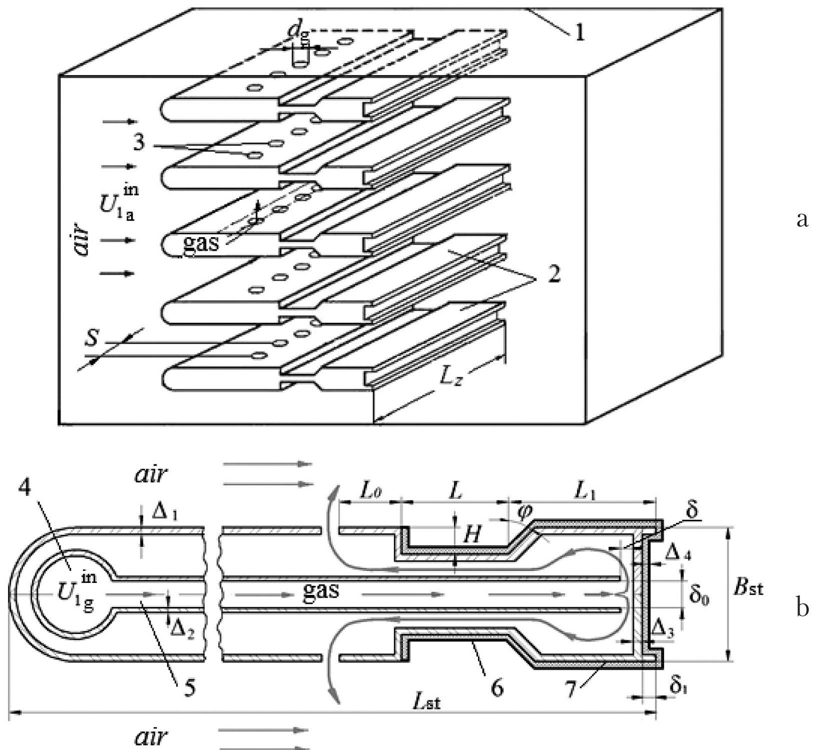

Fig. 1. Scheme of the stabilizer burner device (a) and its cooling system (b): 1 – flat channel; 2 – flame stabilizers; 3 – gas supply holes; 4 – gas supply manifold; 5 – channel for cooling gas; 6 – niche cavity; 7 – coating

cial attention should be given to the operating conditions of microjet burners with the minimum permissible loads of the boiler.

Exposition of the main research material

The typical results of mathematical modeling are shown in Fig. 2–4. The data given correspond to the following initial parameters: natural gas rate $G = 200$ m³/h, which corresponds to 100% of the boiler load; the excess air coefficient was 1.1; the gas temperature at the inlet to the cooling system $t_{in}^{g} = 15$°C; air temperature at the inlet to the burner device $t_{in}^{a} = 20$°C; the wall material of the flame stabilizer is stainless steel; blockage coefficient of the channel cross-section $k_f = 0.3$; diameter of gas supply holes $d = 0,004$ m; the relative step of the arrangement of the holes $S/d = 3.33$; length of the stabilizer $L_{st} = 0.225$ m; width of the stabilizer $B_{st} = 0.030$ m; $L_0 = 0.016$ m; $L = 0.024$ m; $L_1 = 0.033$ m; $\Delta_1 = 0.0015$ m; $\Delta_2 = 0,001$ m; $\Delta_3 = 0,002$ m; $\delta_1 = 0,003$ m; $\delta_0 = 0.006$ m; $\delta = 0.003$ m; coefficient of heat conductivity of the coating material $\lambda_c = 0.8$ W/(m·K); the thickness of the coating is $\Delta_4 = 0.0013$ m.

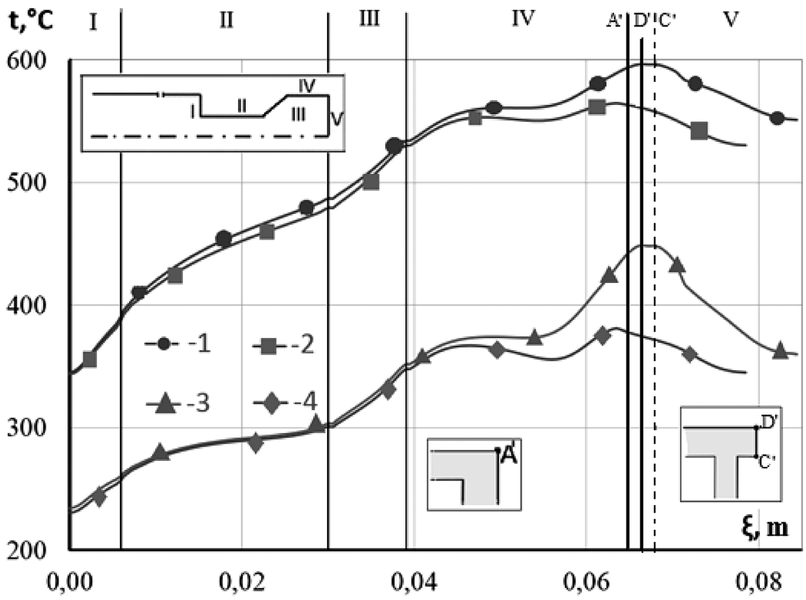

Fig. 2. Temperature distribution along the fragment of the outer surface of the stabilizer wall in the presence (1, 3) and absence (2, 4) of the end protrusion for the relative load of the boiler of 20% (1, 2) and 100% (3, 4)

As evidenced by the data obtained in the absence of thermo-barrier coatings, the temperature of the outer surface of the wall of the flame stabilizer with the end niche at a relative load of the boiler unit of 20% may exceed the permissible level of 550°C, see line 1 in Fig. 2. (Here and below ξ is the coordinate counted from the leading edge of the niche cavity along the outer surface of the flame stabilizer or thermo-barrier coating; the vertical bold lines correspond to the boundaries of the zones I–V on the outer surface of the flame stabilizer, the dashed line correspond to the position of the point C' at the end of the stabilizer). The application of the thermo-barrier coating under consideration somewhat reduces the wall temperature of the flame stabilizer. However, its maximum value t_{max} remains above this permissible temperature, see line 2 in Fig. 3. (The dashed-dot lines in this figure and in Figure 4 correspond to the boundaries of the zones I–V on the outer surface of the coating, the dashed lines correspond to the position of the points C and C' at the stabilizer end).

The maximum values of the temperature on the outer surface of the flame stabilizer wall, as seen from Fig. 3, are observed at the location of the end protrusion. As for the outer surface of the coating, two peak temperatures occur in the region of the protrusion (see lines 1 and 3 in Figure 3). The presence of these peaks is determined by the development of the surface of the coating in this region, which is associated with the end protrusion. Obviously, this circumstance reduces the efficiency of the coating action relative to the decrease in the temperature of the outer surface of the stabilizer wall. In view of the foregoing, it seems advisable to change the configuration of the flame stabilizer, eliminating the end protrusion.

As can be seen from Fig. 2, in the absence of a thermo-barrier coating, the temperature of the outer surface of the flame stabilizer wall without the end protrusion on the end surface and near it is significantly lower than in the case of a stabilizer with a given protrusion. In this case, the location of the maximum value of the wall temperature is shifted somewhat from the end of the stabilizer to its lateral surface. However,

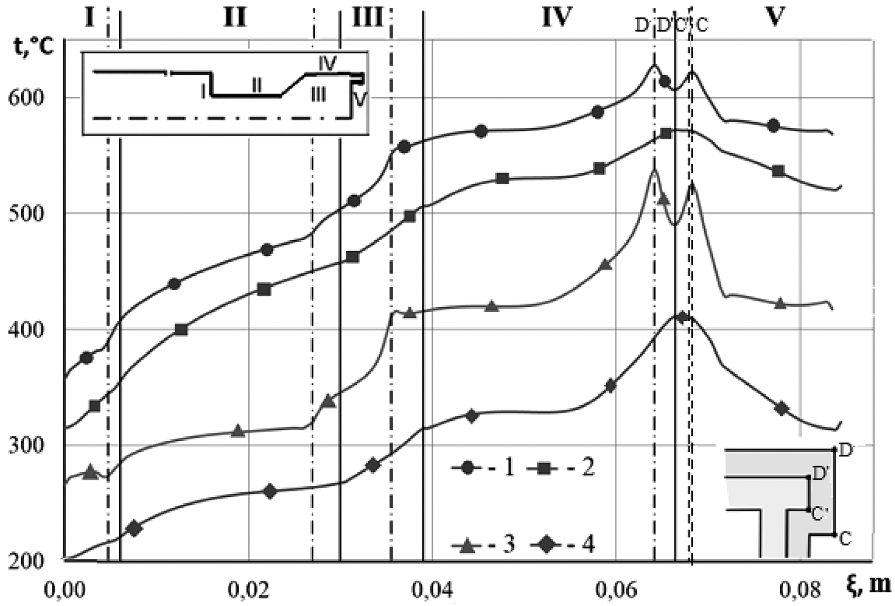

Fig. 3. Temperature distribution along the fragment of the outer (1, 3) and internal (2, 4) surfaces of the thermo-barrier coating of the stabilizer in the presence of the end protrusion for the relative load of the boiler unit of 20% (1, 2) and 100% (3, 4)

the level of this maximum temperature in the absence of end protrusion with a relative load of the boiler 20% remains unacceptably high.

Another picture is observed in the presence of a thermo-barrier coating (Fig. 4). In this case, removal of the end protrusion makes it possible to ensure that the maximum temperature of the outer wall of the flame stabilizer is below the permissible value of 550°C.

Attention is also drawn to the fact that the nature of the change in the temperature of the outer surface of the coating in the presence and absence of the end protrusion is significantly different. (Compare the data in Figures 3 and 4.). Namely, if in the case of a flame stabilizer with an end protrusion in the zone of its location a bimodal peak of temperature is observed, then, in the absence of a protrusion, there is a unimodal temperature peak whose position corresponds to the blunted trailing edge of the stabilizer. The temperature level of this unimodal peak is significantly lower.

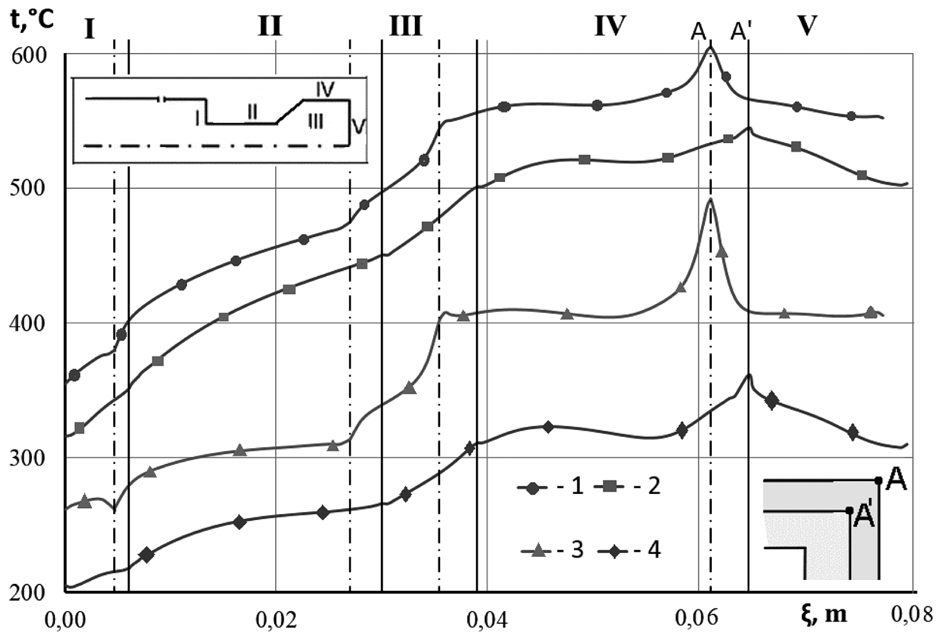

Fig. 4. Temperature distribution along the fragment of the outer (1, 3) and inner (2, 4) surface of the thermo-barrier coating of the stabilizer in the absence of the end protrusion for the relative load of the boiler unit of 20% (1, 2) and 100% (3, 4)

Thus, the elimination of the end protrusion of the flame stabilizer allows to reduce both the maximum temperature of its outer surface, ensuring its acceptable value, and the temperature of the outer surface of the coating. This is explained by the fact that this protrusion, as a factor of development of the surface of the flame stabilizer, significantly reduces the effectiveness of the action of the thermo-barrier coating, not allowing to ensure the required reduction of the wall temperature of the stabilizer.

Conclusion

On the basis of CFD modeling the heat state of the flame stabilizers of microjet burners has been studied in the presence and absence of thermo-barrier coatings in a wide range of the boiler load. Wherein:

1. It is shown that in the absence of thermo-barrier coatings, the temperature of the wall of the flame stabilizers with and without the end niche can significantly exceed the permissible level with a boiler load of 20%.

2. It has been established that the application of a thermo-barrier coating on the outer surface of stabilizers with an end niche does not provide them with the required temperature regime, which is due to a greater extent to the effect of surface development in view of the presence of the end protrusion.

3. Data that indicate that the change in the configuration of the flame stabilizer by removing the end protrusion allows, in the presence of a thermo-barrier coating, to lower the wall temperature of the stabilizer to acceptable values have been obtained.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ТЕМПЕРАТУРНЫХ РЕЖИМОВ ГОРЕЛОЧНЫХ УСТРОЙСТВ СТАБИЛИЗАТОРНОГО ТИПА С ТЕРМОБАРЬЕРНЫМИ ПОКРЫТИЯМИ

Представлены результаты CFD моделирования температурных режимов плоских стабилизаторов пламени микрофакельных горелочных устройств при нанесении на их наружную поверхность термобарьерных покрытий. Выполнен сравнительный анализ теплового состояния стенок стабилизаторов пламени при наличии и отсутствии данных покрытий в широком диапазоне изменения нагрузки котлоагрегата (20...100%). Показано, что при низких нагрузках котлоагрегата температура стабилизаторов пламени с приторцевыми нишами может заметно превышать допустимый уровень как при нанесении защитных покрытий, так и при их отсутствии. Отмечается, что формирование неблагоприятного теплового состояния стабилизаторов с покрытиями обусловлено эффектом развития поверхности, связанным с наличием приторцевого выступа. Рассмотрена возможность обеспечения требуемого температурного режима стенок стабилизаторов пламени путем изменения их конфигурации за счет устранения приторцевого выступа. Показано, что указанное изменение формы стабилизатора пламени позволяет в условиях наличия термобарьерного покрытия снизить уровень его температуры до допустимых величин. [dx.doi.org/10.29010/083.4]

Ключевые слова: *защитные термобарьерные покрытия; тепловое состояние; CFD моделирование; горелочные устройства стабилизаторного типа.*

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