Multiplying the Effect of Nitrogen Oxides Reduction Under Vortex Burner Conditions at Gas Fuel Injection

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***Abstract*—In this paper has been researched the influence of the nozzle's angle of inclination relation to combustion axis on the excess air coefficient of the burning injection device. It is proved that the effect of these parameters taken together significantly decrease the nitric oxide concentration in exhaust flue gas.**

Keywords—nozzles, gas fuel, nitric oxides, burning, injection

I. INTRODUCTION

Modern energy policy is directly related to improving the management of the combustion processes with aim to reduce harmful burning products with highly burning efficiency [3],[4].

No rational combustion management is possible without analyzing the constructive and regime parameters of burning processes and their interconnection.

The physic and chemical processes occurring in the energy devices are complex, interconnected and dynamic.

Diffusion burners with swirling air flow have found the greatest application in the industry.

They are characteristic combustion devices and complex factors do influence on their thermal work, including the possibility to their regulation, in order to increase the efficiency of combustion with minimal environmental pollution.

The degree of rotation of the air flow, after the rotating apparatus defines the conditions of heat and mass transfer in the torch [1] [12] [13] [20] [21], the position of the high temperature zone, as well as the residence time of the reacting components in this area. In this case it is determined by the angle of the nozzle's inclination of the rotating apparatus "**b**".

The coefficient of excess air "a" determines the probability of the presence of free oxygen molecules and their dissociation into atomic oxygen at high temperature.

The intensive development of numerical modeling [2] of combustion processes in recent years provides an effective tool for gas burning researchers and designers.

In our previous studies, the influence of the excess air coefficient and the formation of axial circulation zones on the concentration of NOx during combustion of gaseous fuels under conditions of injection and vortex combustion devices was established.

In [8] it is found that the coefficient of excess air has an ambiguous effect on NOx emissions - they increase to a certain value of **a**, and then decrease. The concentration of thermal nitrogen oxides has a pronounced maximum at **a** = 1,18-1,2, Fig. 1. From an economic point of view, it is advisable to realize the reduction of NOx emissions, changing **a** from 1,04 to 1,12.

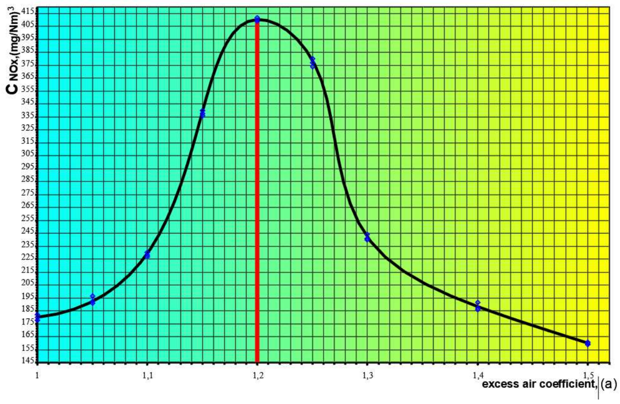

Fig. 1. NOx emission in a function of coefficient of excess air.

In [6] [8] [9] through numerical modeling it is shown that the reduction of NOx emissions is accompanied with development of axial circulation zones Fig. 2 and Fig. 3 that cool the flame front.

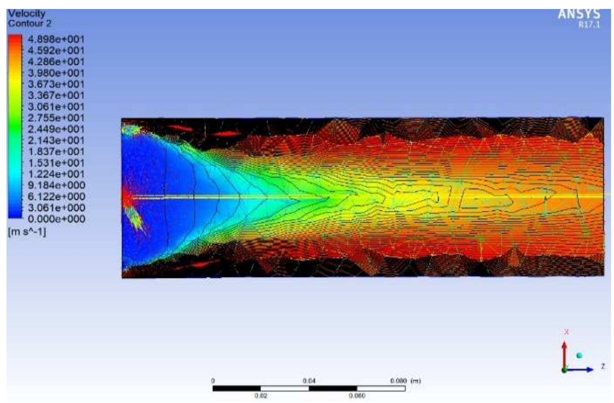

Fig. 2. *Velocity contour distribution in mixing chamber at nozzle angle "b=45°".*

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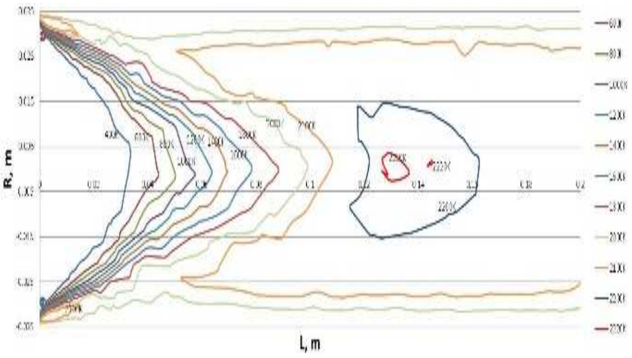

Fig. 3. *Temperature contour distribution in mixing chamber at nozzle angle "**b**=45°".*

The rotated gas torch [6] [18] is formed by injection, through a system of nozzles arranged at a certain angle relative to the cross section of the burner.

In the specialized literature, the basic principle for producing swirled injected jet is known., as well as is shown on Fig. 4. According to the scheme of Fig. 4, active gas jets flow out at high pressure from the nozzles rotated to the axis of the burner Fig. 5. As a result of the dilution, air from the surrounding area is injected into this area. Both streams burn diffusely form a rotated gas torch.

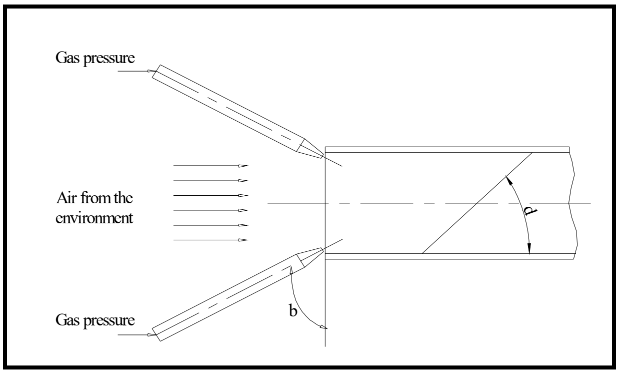

Fig. 4. *Sheme for injected swirled gas flow.*

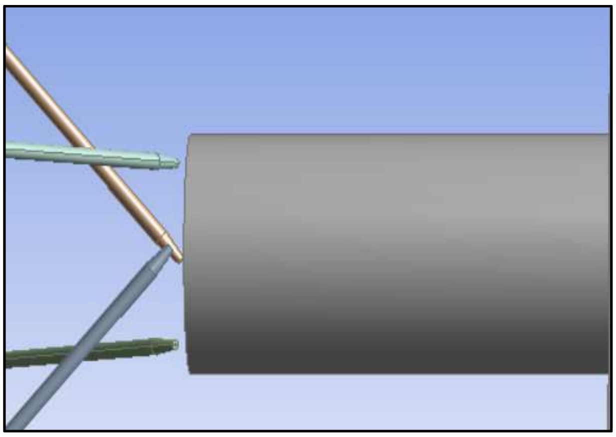

Fig. 5. *Geometric model for injected swirled gas flow.*

Profiles of a burning gas torch in the open space were obtained on a combustion device with variable constructive parameters located in the Faculty of Engineering and Pedagogy – Sliven - Fig. 6, Fig. 7. The burning profiles are formed from rotated injected jet at different angles of the nozzles by direct photographing and shown in Fig. 8.

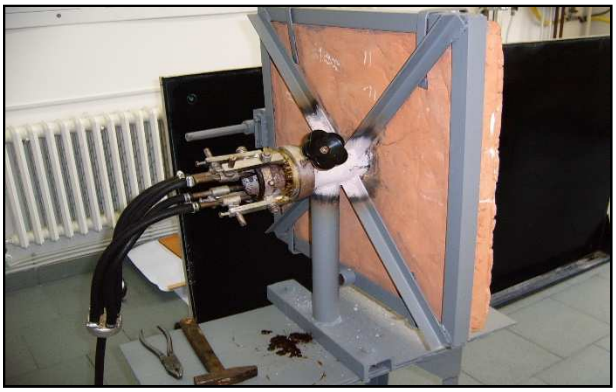

Fig. 6. *Experimental system with the possibility of creating a radial jet-back view.*

Fig. 7. *Experimental system with the possibility of creating a radial jet-front view.*

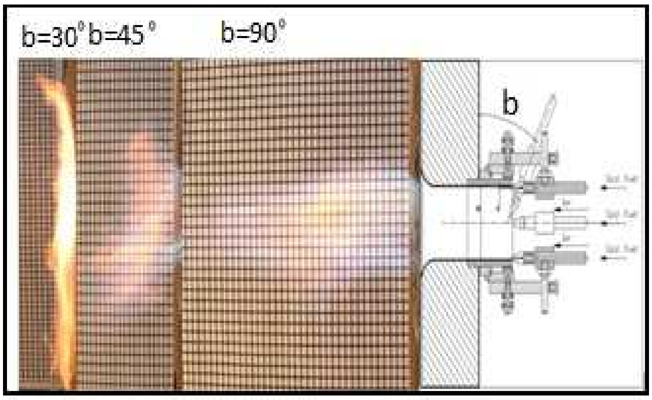

Fig. 8. *Profiles of a burning gas torch obtained by direct photographing.*

The figure clearly shows that when the angle of inclination of the nozzles is varied, the length of the flame is steadily decreasing and it becomes flat torch.

A characteristic feature that is observed is the appearance of typical signs of a circulating zone in the axial part at angle **b** = 45°. By changing angle **b** below this value, the rotated gas torch goes into a radial jet.

The circulation axial zone formed at a fixed angle of the gas nozzles, gives the cooling effect on the flame front and it is a precondition for influencing of "thermal" nitric oxides formation [5] [19].

Another feature of this type of combustion device with variable constructive parameters is the relationship between the injection coefficient (excess air coefficient) and the geometric dimensions of the gas nozzles and the toroid-shaped central hole [7] [11] in the refractory plate acting as a mixer according to equation (1):

$$\frac{S_{gas}}{S_{mixer}} = \frac{cos(90-b)+u\cdot m}{(1+u)\cdot(1+u.c)\cdot\left(cos\, d+\frac{z}{2\, cos\, d}\right)} \qquad (1)$$

where:

S_{gas} - cross-sectional area of the gas nozzles;

S_{mixer} - cross-sectional area of the mixer;

- $c = \frac{r_{gas}}{r_{air}}$ - ratio of gas and air densities;

- z - the aerodynamic resistance of the burner;

- $u = \frac{M_{air}}{M_{gas}}$ - air / gas mass flow ratio (mass injection coefficient);

- $m = \frac{W_{air}}{W_{gas}}$ - air / gas velocity flow ratio;

- b - angle between the cross section (refractory plate) of the burner and the gas nozzles;

- d - angle between the real velocity vector of the rotated jet and the axial axis of the burner Fig. 4.

Equation (1) shows that by changing both the coefficient of excess air and formation of axial circulation zones, the emissions of "thermal" nitrogen oxides in the combustion products can be reduced.

II. Problem Definition

The purpose of the present work is to experimentally investigate the possibility with a burner with variable design parameters, to multiply the effect of reducing the nitrogen oxides emissions with their simultaneous influence.

III. Main Part

The laboratory installation described in [6] was used, and it should be noted that the dimensions of the combustion chamber are in accordance with the obtained profiles of the burning torch in Fig. 8.

A gas analysis was performed to determine the content of nitrogen oxides in the combustion products.

To determine the dependence of the excess air coefficient **a** from the nozzle angle **b** as a consequence of the basic calculation equation (1), a preliminary laboratory experiment was conducted.

Gas flow rate - technical propane maintained at a constant B_{gas} = 2,1 m^3/h during the individual tests.

The design of the swirling mechanism allows a steplessly change of the angle of inclination of the nozzles **b** through a conical gear.

The gas analysis was performed with a gas analyzer type TESTO-300-M, ISO 9001 certified.

An industrial rotameter type PC-5L, № 0E19 was used to determine the gas flow.

For control of the flue gas temperature a thermocouple probe NiCr-Ni, according to DIN (K type) is used.

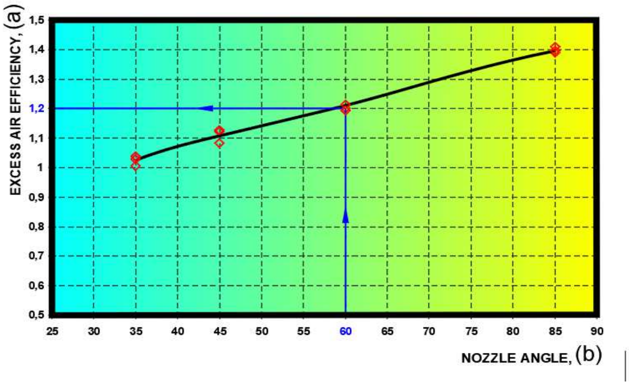

Fig. 9. *Dependence of the coefficient of excess air "a" from the angle of inclination of the nozzles of injection vortex burner.*

The excess air coefficient **a** is determined by the free oxygen in the combustion products taken from the gas analyzer.

The results of the experiment are shown graphically in Fig. 9.

It can be seen from Fig. 9 that, when passing from swirling to direct flow, the coefficient of excess air **a** increases as a confirmation of (1).

To determine the simultaneous influence of these two parameters on the formation of nitrogen oxides in a burning torch of an injection vortex burner under the same conditions, another experiment was conducted.

The continuous gas analysis of the combustion products is performed in the output of the gas chamber, changing these two parameters simultaneously.

In order to obtain adequate results, the study was performed with triplicate experiments. No significant deviations were observed in the results.

Fig. 10 shows the variation of the NOx emissions in the combustion products at different angles of inclination of the gas nozzles corresponding with values of the coefficient of excess air in Fig. 9.

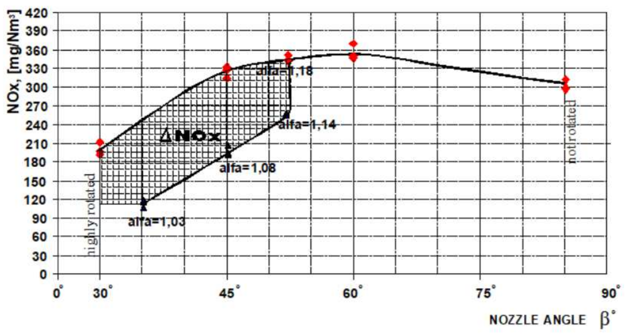

Fig. 10. *Dependence of NOx emissions in the combustion products from the angle of inclination of the gas nozzles "b" and the coefficient of excess air "a" of the injection vortex burner.*

Fig 10 shows an initial increase of the NOx emissions when passing from direct flow to a low-swirling jet, defining a maximum value at an angle **b** = 60°, and a subsequent decrease in NOx emissions.

Comparing the dependence of this figure with the previously obtained profiles of the burning torch, it can be seen that, at an angle of **b** = 45-52 °, there are typical features of the axial circulation zone.

At the intermediate value of the angle of inclination of the blades **b** = 52 ° in the presence of an axial circulation zone, the coefficient of excess air is reduced by changing the ratio S_g / S_m under the same other conditions. In this case, in addition to the cooling effect, the concentration of oxygen molecules in the reacting zone is also limited in the self-studies performed by the axial circulation zone, which leads to low NOx emission levels [14], [15], [16], and [17].

The effect of the simultaneous effect of these two parameters on NOx emissions is shown in Fig. 10 with the shaded area.

IV. CONCLUSIONS

The dependence of the excess air coefficient on the angle of inclination of the nozzles has been experimentally obtained of an injection flat-flame burner, which confirms the consequence of the basic calculation equation of this type of combustion devices.

In the working variant of an injection vortex burner, the change of the coefficient of excess air realized by changing the angle of inclination of the nozzles has a significant effect on the NOx concentration in the combustion products. The tendency for local emission maximum at **a** value close to 1,2 is preserved.

With a certain ratio of the cross-section of the mixer and the total area of the gas nozzles of the injection vortex burner and a suitable combination with the angle of inclination of the nozzles defining the degree of rotation, a reduction of NO_x emissions in the combustion products can be realized from 20 up to 50%.

The obtained results make it possible to properly adjust the operation (regime and constructive parameters) of existing combustion devices of this type, in order to protect the environment from the harmful effects of NO_x emissions.

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