Modeling of a burning process in a limited turned injected stream

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***Abstract* – This report examines the digital research possibility of a gas fuel burning in a turned limited stream of oxidizer prepared in an injected way. A computer program has been applied that is based on the "mixing length hypothesis" of Kolmogorov-Prandtl. A part of the received results are presented as basic parameters of the torch. A summary of some results of different turning degrees has been considered and a conclusion has been made on the possible regulations of torch parameters.**

***Key words* – numerical modeling, injected turned stream, gas fuel**

I. INTRODUCTION

The injected turned stream is formed under the influence of nozzles situated under a solid angle in relation to internal cylindrical surface.

The several nozzles leave out compressed air and it is due to part of its kinetic energy that air from the surrounding is drawn in and a limited turned stream is formed. If we add gas fuel to the turned air stream, burning device is made that can be successfully applied in cases where it is not expedient to use a fan. The advantages of such burning devices are presented in [1].

Figure 1 schematically shows a burning device that forms a limited turned gas torch. The aerodynamic research under isothermal conditions, carried out by the authors, show that by alternation of β angle, it is possible to alternate the aerodynamics of the turned stream. The tangential and axial velocity components are chiefly alternated as well as the stream static pressure as well [2].

The objective of the present report is through computer simulation to research the possible ways to influence the burning process by nozzles β angle alternation. Such information would be very useful in respect of the burning process regulation under real conditions.

II. NUMERICAL INVESTIGATION

A. Mathematical pattern

The differential equations that reflect mass, energy and movement quantity preservation laws are presented in a description suggested by D.B.Spalding.

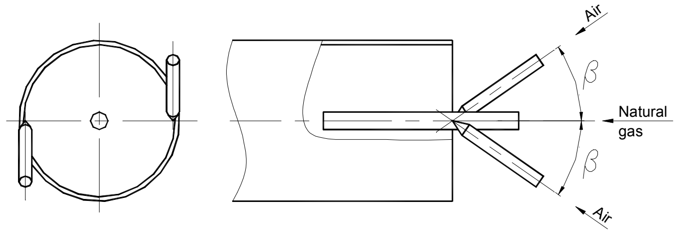

Fig. 1. Scheme of injected turned stream formation

Velocity vortex equation:

$$r^2\cdot\left\{\frac{\partial}{\partial z}\left(\frac{\Omega}{r}\cdot\frac{\partial\psi}{\partial r}\right)-\frac{\partial}{\partial r}\left(\frac{\Omega}{r}\cdot\frac{\partial\psi}{\partial z}\right)\right\}-\frac{\partial}{\partial z}\left\{r^3\cdot\frac{\partial}{\partial z}\left(\mu_{ef}\cdot\frac{\Omega}{r}\right)\right\}-$$
$$-\frac{\partial}{\partial r}\left\{r^3\cdot\frac{\partial}{\partial r}\cdot\left(\mu_{ef}\cdot\frac{\Omega}{r}\right)\right\}- \qquad (1)$$
$$-r\cdot\frac{\partial}{\partial z}\left(\rho\cdot w^2\right)-r\cdot\frac{\partial}{\partial z}\left(\frac{u^2+v^2}{2}\right)\cdot\frac{\partial\rho}{\partial r}+r^2\cdot\frac{\partial}{\partial r}\left(\frac{u^2+v^2}{2}\right)\cdot\frac{\partial\rho}{\partial z}=0$$

Movement quantity momentum preservation equation:

$$\frac{\partial}{\partial z}\left(r\cdot w\cdot\frac{\partial\psi}{\partial r}\right)-\frac{\partial}{\partial r}\left(r\cdot w\cdot\frac{\partial\psi}{\partial z}\right)-$$
$$-\frac{\partial}{\partial z}\left\{r^3\cdot\mu_{ef}\cdot\frac{\partial}{\partial z}\left(\frac{w}{r}\right)\right\}-\frac{\partial}{\partial r}\left\{r^3\cdot\mu_{ef}\cdot\frac{\partial}{\partial r}\left(\frac{w}{r}\right)\right\}=0 \qquad (2)$$

Burning equation:

$$\frac{\partial}{\partial z}\left(\varphi_{fu}\cdot\frac{\partial\psi}{\partial r}\right)-\frac{\partial}{\partial r}\left(\varphi_{fu}\cdot\frac{\partial\psi}{\partial z}\right)-$$
$$-\frac{\partial}{\partial z}\left(\frac{\mu_{ef}}{Pr}\cdot r\cdot\frac{\partial\varphi_{fu}}{\partial z}\right)-\frac{\partial}{\partial r}\left(\frac{\mu_{ef}}{Pr}\cdot r\cdot\frac{\partial\varphi_{fu}}{\partial r}\right)=0 \qquad (3)$$

Dependence between velocity vortex and streamline function:

$$\frac{\partial}{\partial z}\left(\frac{1}{\rho\cdot r}\cdot\frac{\partial\psi}{\partial z}\right)+\frac{\partial}{\partial r}\left(\frac{1}{\rho\cdot r}\cdot\frac{\partial\psi}{\partial r}\right)+\Omega=0 \qquad (4)$$

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B. Numerical model

The differential equations are transformed through orthogonal net with uniform step and they are integrated on terminal areas with suggestion of specific distribution of variable quantities among assemblies.

C. Results from the numerical experiment

The burner shown on fig.1 is presented in a generalized appearance on fig. 2. In order to accomplish the digital experiments, the marked dimensions have the following values: $D_3=D_4=D_5=104$ mm; $D_8=28$ mm; $D_{11}=24$ mm.

The velocity of the fuel and oxidizer in direction of the burning chamber axis are respectively: u_f and u_o, and the following values are accepted for the experiment: $u_f = 40$ m/s, $u_o = 20$ m/s.

In the burning device before the beginning of the process, a turned stream is formed, as a result of the active air streams and the added air from the surrounding positioning. Thus one of the recommendations for a better adequacy of the pattern in [3] is met. The geometrical values of the burner body and the nozzles guarantee minimal coefficient of air surplus of the order of 1,04. The foreseen fuel in the experiment is natural gas.

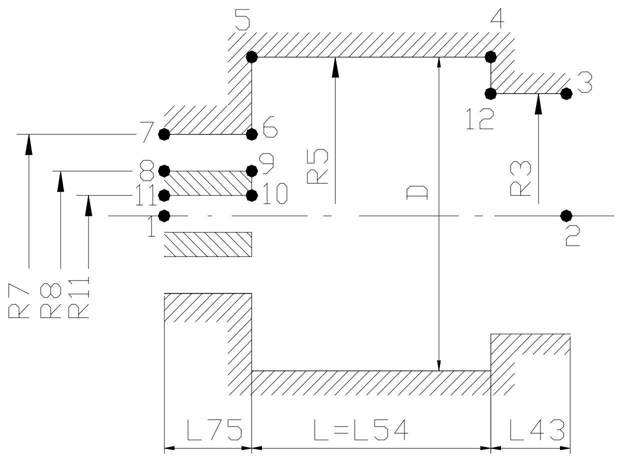

Fig. 2. Generalized scheme of the burning chamber configuration with specific geometrical dimensions.

At primary velocity conditions introduction, the experimental results of the injected turned stream by the authors are used. More specifically, the values of the tangential and axial components are averagely the integral values, got through integrating of the velocity fields at the entrance of the burning device when the turned stream has already been formed. As a criterion of the degree of turning characterization, the relation $s = \frac{\bar{w}}{\bar{u}}$ is used where $\bar{w}$ and $\bar{u}$ are averagely the integral values of the tangential and axial components. In conformity with the experiment the degree of turning s is alternated within the limits of 0 – 1,3.

Figures 3, 4, 5, 6, 7 and 8 show the results from the numerical experiment for degree of turning s=1.

At other degrees of turning similar in quality results are achieved. The juxtaposition of isotherm distribution shows a substantial alternation in the dimensions of the burning front in the torch. As the degree of turning increases, the surface of burning decreases.

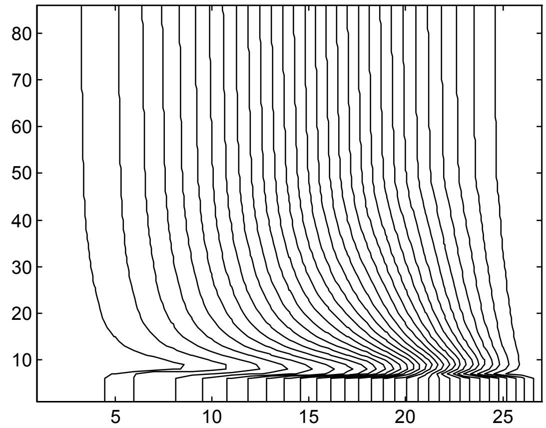

Fig. 3. Results from the digital experiment at s=1 streamline function

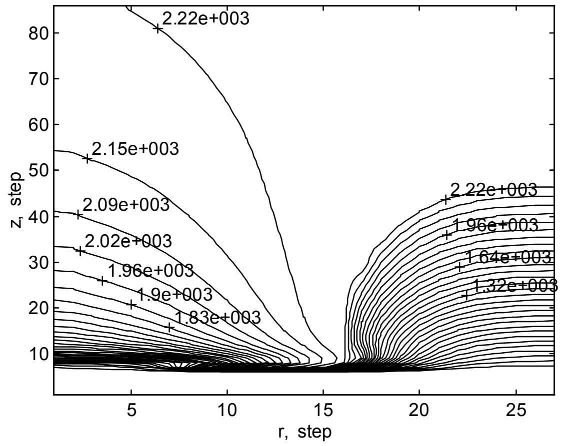

Fig. 4. Results from the numerical experiment at s=1 – isotherms

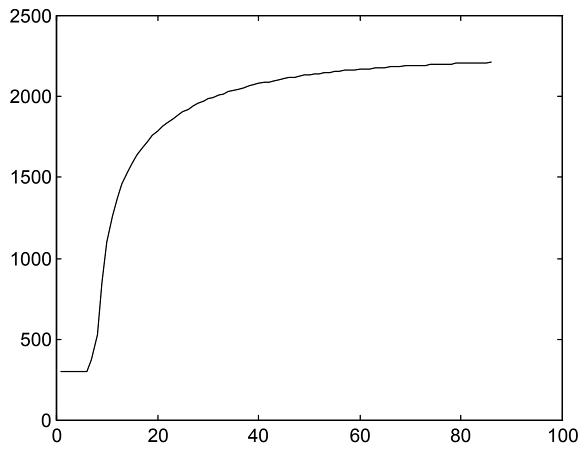

Fig. 5. Results from the numerical experiment at s=1 – temperature alternation along the burning chamber axis.

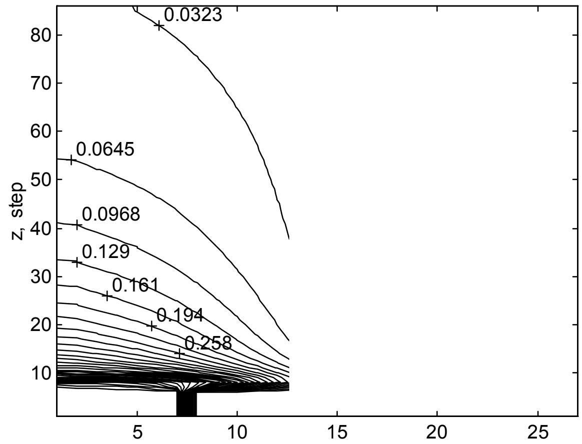

Fig. 6. Results from the digital experiment at s=1 – isolines of the fuel mass concentration

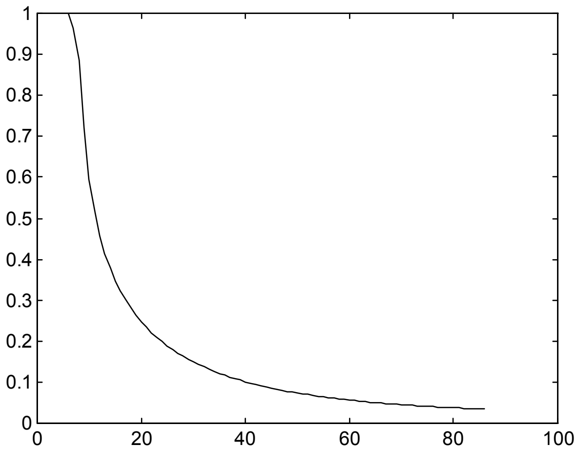

Fig. 7. Results from the numerical experiment at s=1 – alternation of fuel mass concentration along the burning chamber axis

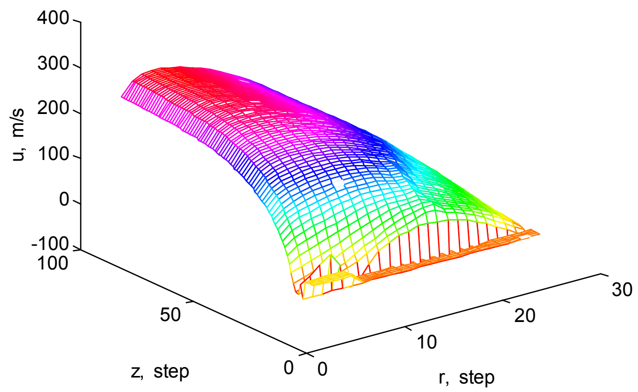

Fig. 8. Results from the digital experiment at s=1 – alternation of the velocity axis component in the burning chamber.

D. Summary and conclusion

A peculiar interest for the practice is the alternation of fuel concentration along the longitudinal axis of the torch that gives an idea of the burning intensity and its chemical length.

From practical point of view the chemical length of the torch is an important parameter at burning devices designing and their regulation.

Figure 9 shows the dependence between the relative torch length l/D_3 and the stream turning s at the section of fuel introduction.

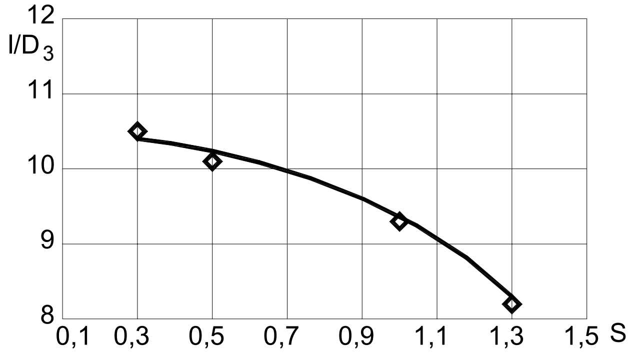

Fig. 9. Alternation of the relative torch length in dependence of the turning degree.

At l determination, it is accepted that this is the length along the axis of the burner at which the fuel concentration reaches a value of approximately 0,03. The dependence shows that by the turning degree increasement, the chemical length of the torch changes substantially. The practical value of this result is that actually we determine the possibilities of regulation the torch length under given conditions, only at the expense of Ћ angle. It is certainly evident that at the injected stream these possibilities are not small.

The achieved results present a serious motive in favor of applying burning devices with alternative construction parameters.

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