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ÚPRAVA, VÝPOČET A EXPERIMENTÁLNÍ NASTAVENÍ HOŘÁKU, URČENÉHO PRO SPALOVÁNÍ METANU V ELEKTRICKÉM POLI

CORRECTION, CALCULATION AND EXPERIMENTAL ADJUSTMENT OF BURNER, DESTINED FOR BURNING METHANE IN ELECTRIC FIELD

Abstract

In this paper was solved modification of combustion burner for experimental exam of methane combustion in the electric field with high intensity voltage. The burner was originally designed for the combustion stack gas. The burner must have been necessary adjusted, because the mixture of stack gas and air was replaced by mixture of methane and oxygen. The fundamental requirement is to adjust the height of the flame that may reach a maximum of height 100 mm. This height was required because the application of electric field intensity with the maximum voltage of 100 kV. Another objective was to achieve a geometrically stable methane-oxygen flame. Gas mixture of methane and oxygen were chosen because the simplicity of combustion reactions. This paper includes a detailed description of stack gas burner, the recalculation of the parameters for a mixture of methane and oxygen with the calculation of flow rate regulation for individual gasses, calculation of flow velocity and differential pressure. From the results of calculations and using the experimental configuration, the burner was configured on flow rate 0.1045 $m^3 \cdot h^{-1}$ of oxygen and 0.051 $m^3 \cdot h^{-1}$ of methane and pressures 2 bar for methane and 5.9 bar for oxygen, which corresponds to approximately power of burner 0.5 kW. At this setting, the flame showed a perfect geometry and flame height for the subsequent application of high intensity electric field to the flame zone.

Abstract

V této práci byla řešena úprava hořáku pro experimentální úlohu spalování metanu V elektrickém poli O vysoké intenzitě napětí. Hořák byl původně určený pro spalování vysokopecního plynu. Hořák bylo nutné upravit Z důvodu záměny směsi vysokopecního plynu se vzduchem za směs metanu S kyslíkem. Stěžejní podmínkou bylo upravit výšku plamene tak, aby dosahoval maximální výšky 100 mm. Výška byla požadována Z důvodu aplikace elektrického pole O intenzitě napětí max 100 kV. Dalším cílem bylo dosažení geometricky stabilního metanovo-kyslíkového plamene. Směs plynů metanu a kyslíku byla zvolena Z důvodu jednoduchosti reakce hoření. Článek zahrnuje podrobný popis hořáku na vysokopecní plyn, přepočet jednotlivých parametrů pro směs metanu S kyslíkem, dále výpočet regulace průtoků jednotlivých plynů, výpočet rychlosti proudění a rozdílu tlaku. Z výsledků výpočtů a pomocí experimentálního nastavení, byl hořák upraven na průtoky 0,1045 $m^3 \cdot h^{-1}$ kyslíku a 0,051 $m^3 \cdot h^{-1}$ metanu a tlaky 2 bar pro metan a 5,9 bar pro kyslík, což odpovídá výkonu hořáku cca 0,5 kW. Při tomto nastavení plamen vykazoval ideální geometrii a výšku plamene pro následnou aplikaci elektrického pole O vysoké intenzitě do zóny plamene.

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1 INTRODUCTION

Modification of burner which was originally designed for burning of stack gas it is one of the very important parts of the prepared experiment with process of combustion in the presence of electric field. It was necessary to modificate the burner and set the parameters to be able to burn a mixture of methane and oxygen. This gas mixture was chosen because the simplifying of combustion reactions. High repeatability of the experiment was ensure by taking methane and oxygen from cylinders with guaranteed purity (99.95 % purity of methane, 99.95 % purity of oxygen). In publication [1] were mentioned that they used for similar application intensity of voltage 1 kV on distance 1 mm. Given that we have a source with a maximum voltage of 100 kV, the height of the flame was limited to maximum 100 mm. Another required parameter is the geometric stability of the flame. The values of all the settings which will be calculating are shown in Fig. 1, which shows the proposal of the whole experiment.

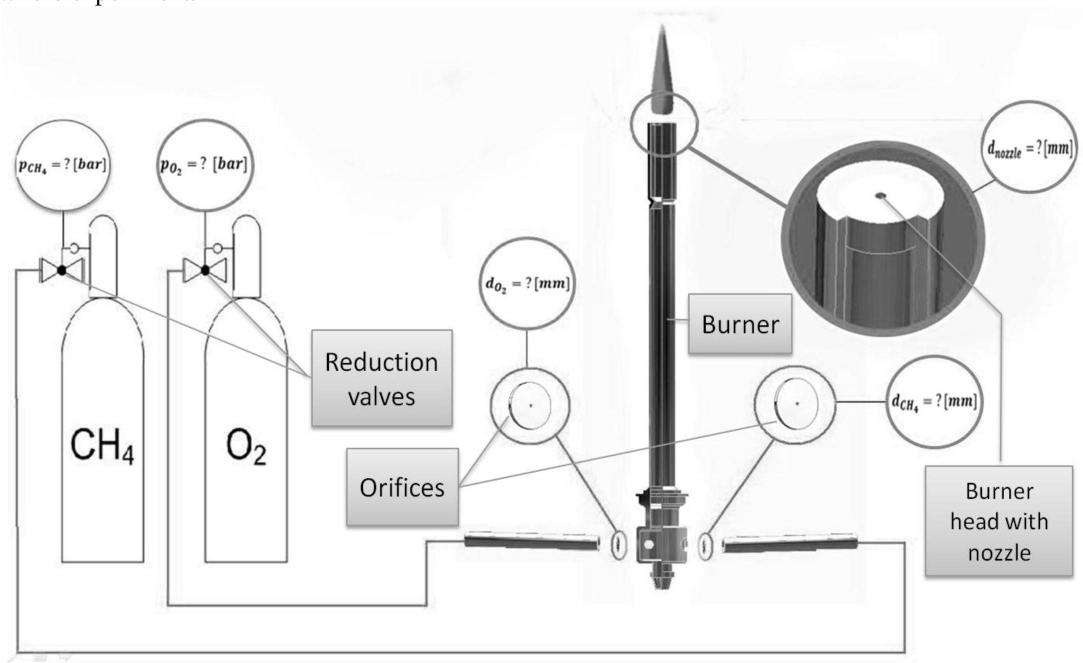

Fig. 1 Schematic arrangement of experiment with all unknowns values of magnitudes.

2 DESCRIPTION OF STACK GAS BURNER.

It was originally a 4 kW burner which was described in Fig. 2. The burner was proposed for burning stack gas.

Heating value of stack gas is around 4,000 kJ.m^{-3}. Composition of stack gas and its other properties are listed in Table 1.

Tab. 1 – Composition of stack gas. [2]

Parameters	Unit	Value
Part by volume of carbon monoxide (CO)	-	23 – 29 %
Part by volume of carbon dioxide (CO_2)	-	8 – 13 %
Part by volume of hydrogen (H_2)	-	2 – 5 %
Part by volume of Nitrogen (N_2)	-	55 – 63 %
Volume density	kg·m^{-3}	1.16
Theoretically, the required amount of air	m^3·m^{-3}	0.7
Lower limit of heating value	kJ·m^{-3}	3371
Calorific value of the stoicheiometric compound with air	kJ·m^{-3}	1968

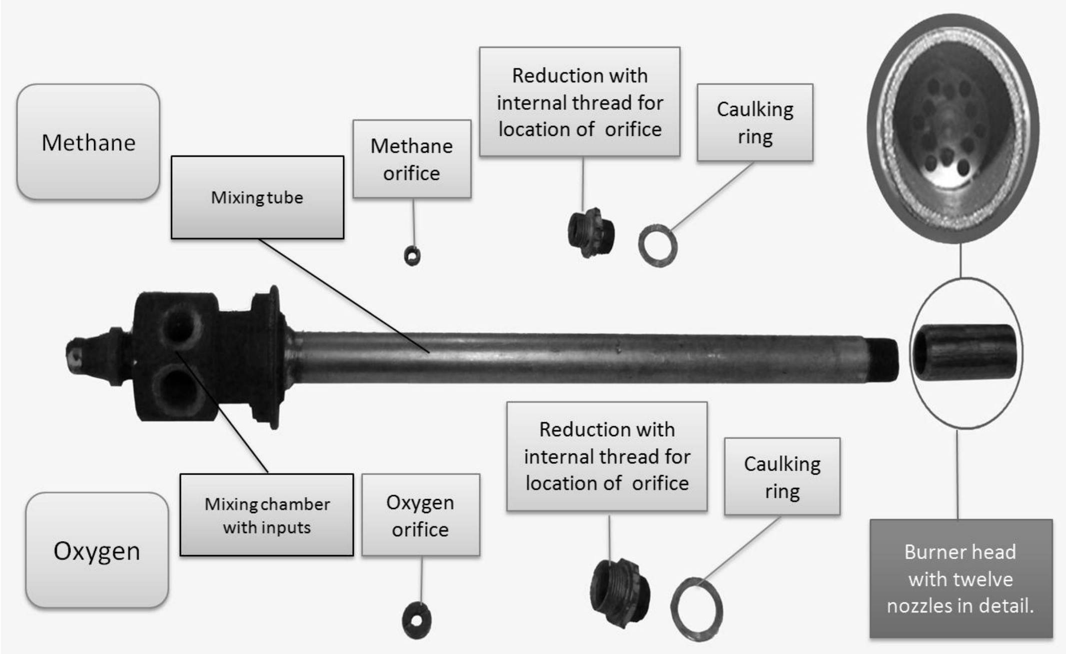

Fig. 2 Old burner with set power by orifices 4 kW, fit for combustion of stack gas.

Burner for combustion of stack gas has two inlet inputs for individual gases, which are proposed perpendicular to the axis of the burner and has inclined angle 75° with each other, which is shown in Fig. 3.

Fig. 3 Detail of burner inputs.

Each input has its own reduction part, in which is located orifice, through which is regulated, depending up on pressure and orifice-opening diameter, flow rate of gas into the mixing chamber. The mixing chamber (has a cylindrical shape) is at the bottom of the burner. The mixing chamber is connected to the mixing tube with an inside diameter of 16 mm, which is topped with a burner head. The burner head has twelve nozzles, each with inside diameter 2 mm. Fig. 4 shows that the rotation axis of the burner head has inclined angle of 15° with each axes of nozzles.

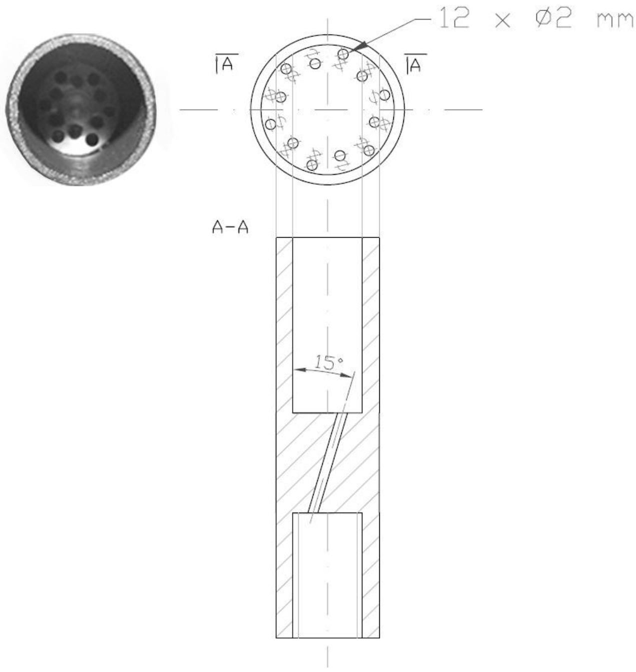

Fig. 4 Burner head with twelve nozzles.

3 CALCULATION OF GAS FLOW RATE ON BASICS REQUIRED OF BURNER POWER

Initial setup of burner was designed for combustion of stack gas with air, now must be taken into account the combustion process - methane with oxygen. Stack gas, as already mentioned, has a calorific value around 4000 kJ.m^{-3}. Considering with methane calorific value 35 000 kJ.m^{-3}. The basic calculation is calculation of methane flow rate. The first experimental burner adjusting was done for burner power 0.5 kW. This calculation is done in equation (1) [3]:

$$V_P = \frac{3600.P_h}{H} \qquad (1)$$

where:

V_P – desired gas flow rate through burner $\left[m^3.h^{-1}\right]$,

P_h – power of burner $\left[\mathrm{kW}\right]$(P_h = *0,5 kW*),

H – calorific value of methane $\left[\mathrm{kJ.m^{-3}}\right]$($H$ = *35000 kJ.m*$^{-3}$).

By calculation there was determined flow rate of methane $V_{P\ methane}$ = 0.0514 m^3·h^{-1}.

4 CALCULATION OF FLOW VELOCITY, ORIFICE-OPENING DIAMETER AND DIFFERENTIAL PRESSURE Δp FOR METHANE.

If we know the desired flow rate of gas, we can determine orifice-opening diameter and we are able to calculate flow velocity of gas through the orifice. Let's consider a circular diameter of orifice. The calculation of flow velocity is given in equation (2):

$$v_m = \frac{V_P}{\frac{\pi . d^2}{4}} \tag{2}$$

where:

v_m – methane flow velocity in orifice $[\mathrm{m.s^{-1}}]$,

V_P – desired gas flow rate through burner $[m^3.s^{-1}]$ *(V_p = 1,43.10^{-5} m^3.s^{-1})*,

d – orifice-opening diameter $[\mathrm{m}]$(*d = 2.10^{-4} m*),

From the calculation there was determined that the gas flow velocity through the orifice with orifice-opening diameter 0.2 mm is 455 m·s^{-1}. Based on the knowledge of the flow velocity through the orifice and density of gas flowing through orifice, and by using equation (3), the pressure difference was calculated. This pressure difference was set on the control valve to guarantee calculated flow rate of gas:

$$\Delta p = \frac{{v_m}^2}{\eta^2 . 2 . \rho} \tag{3}$$

where:

Δp - pressure difference $[\mathrm{Pa}]$,

v_m – methane flow velocity in orifice $[\mathrm{m.s^{-1}}]$ (v_m = *455 m.s^{-1}*),

η – efficiency of orifice [-] (η = *0,71*)[4],

ρ – density of gas $[\mathrm{kg.m^{-3}}]$ (ρ = *0,6784 kg.m^{-3}*).

Efficiency of orifice is determined from the table values [4] and depends on the profile of orifice. Substituting into equation (3), there was defined the difference of pressure Δp = 0.303·10^6 Pa, which is after rounded down 3 bar.

5 CALCULATION OF FLOW VELOCITY, ORIFICE-OPENING DIAMETER AND DIFFERENTIAL PRESSURE Δp FOR OXYGEN.

In settings of values for oxygen, we use the basic chemical equation (4). From this equation is known, that if we would like to burn 1 mole of methane, we must add 2 moles of oxygen.

$$CH_4 + 2O_2 = CO_2 + 2H_2O \tag{4}$$

From the basic chemical equation for burning methane and oxygen resulting gas ratio is 1:2, which was corrected in practice for reasons of complete combustion with a surplus oxygen of 5 % [5]. It follows that the ratio is modified on ratio 1: 2,05. Therefore, the required flow rate of oxygen is 0.1045 m^3·h^{-1}.

In calculating the oxygen flow velocity, in depending on the orifice-opening diameter, the procedure using equation (2) was used. By calculation there was set speed 933 $m \cdot s^{-1}$, at orifice-opening diameter 0.2 mm. To calculate the pressure difference Δp there was used equation (3), where we consider the density of oxygen in the gas phase 1.43 $kg \cdot m^{-3}$. By calculating there was determined the pressure difference Δp for oxygen $0.602 \cdot 10^6$ Pa, which is after a round down 6 bar. Table 2 shows the calculated parameters of adjustment.

Tab. 2 Calculated parameters of adjustment.

Parameters	Methane	Oxygen
Flow rates V_P [$m^3 \cdot h^{-1}$]	0.051	0.1045
Orifice-opening diameters d [mm]	0.2	0.2
Differentials pressures Δp [bar]	3	6

6 CALCULATION OF FLOW VELOCITY GAS MIXTURE IN NOZZLE OF BURNER HEAD.

In the framework modification of burner for experiments with an electric field, the burner head was modified to one central nozzle with the view of burning only one flame. Before the experimental testing, it was necessary to modify the burner head. In the burner it was necessary to weld up all 12 nozzles and then drill one 2 mm central hole (nozzle). This created space for one, ideally burning flame above the burner head. Modification of burner head on one central nozzle is shown in Fig. 5.

Fig. 5 Modificated burner head with one nozzle with diameter 2 mm.

Velocity of burning methane is 4,5 $m.s^{-1}$. Therefore, flow velocity of mixture through the burner head must exceed this speed to prevent blow-back to the burner. The flow velocity of gas in the burner head was calculated by equation (5).

$$v = \frac{V_{P_{metanu}} + V_{P_{kysliku}}}{S_{trysky}} \tag{5}$$

where:

v – velocity of gas mixture $\left[m.s^{-1}\right]$,

$V_{P_{methane}}$ – desired flow rate of methane $\left[m^3.s^{-1}\right]$ ($V_{Pmethane} = 1,428.10^{-5}\ m^3.s^{-1}$),

$V_{P_{oxygen}}$ – desired flow rate of oxygen $\left[m^3.s^{-1}\right]$ ($V_{Poxygen} = 2{,}929.10^{-5}\,m^3.s^{-1}$),

S_{nozzle} – area of nozzle $\left[\mathrm{m}^2\right]$ ($S_{nozzle} = 3{,}14.10^{-6}\,m^2$).

By calculations, it was determined flow velocity in the burner head nozzle 13.88 $m{\cdot}s^{-1}$. Burning velocity of methane, as already stated is 4,5 $m.s^{-1}$, therefore it can not generate the blow-back of gas.

7 BURNER LAUNCHING AND TESTING

The next step was the production of orifices for oxygen and methane on the basis of the above calculations. As a material for the production of orifices for oxygen served brass plate with a thickness of 1 mm, from which the circular shape with a diameter of 15 mm was made. Internal hole was drilled through the drill with diameter 0.2 mm. For methane orifice with diameter 10 mm there was used copper sheet with a thickness 1 mm, which was drilled in the middle hole of 0.2 mm. Both orifices are shown in Fig. 6.

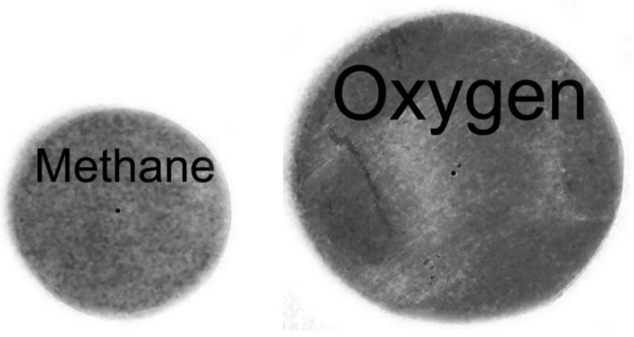

Fig. 6 Orifices for each one gasses.

Holes in the orifices were remeasured using microscope Neophot 2, see in Fig. 7.

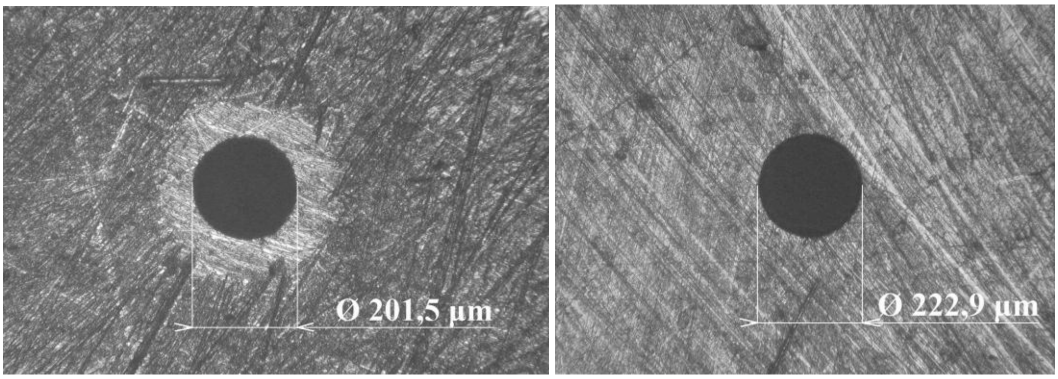

Fig. 7 On the left side - Detail of oxygen orifice with hole diameter 201,5μm. On the right side - Detail of methane orifice with hole diameter 222,9 μm (both pictures are 100 x zoom).

After the precise remeasurement of the holes, see in Fig. 7, there must be recalculated all set orifices values with according to the equations (1, 2, 3, 4). The resulting values are listed in Tab. 3.

Tab. 3 More accurate and recalculated values for adjusted power 0.5 kW.

Parameters	**Methane**	**Oxygen**
Flow rates V_P [$m^3 \cdot h^{-1}$]	0.051	0.1045
Orifice-opening diameters d [mm]	0.2229	0.2015
Differentials pressures Δp [bar]	2	5.9

Fig. 8 presents setup of experimental values before ignition of the burner.

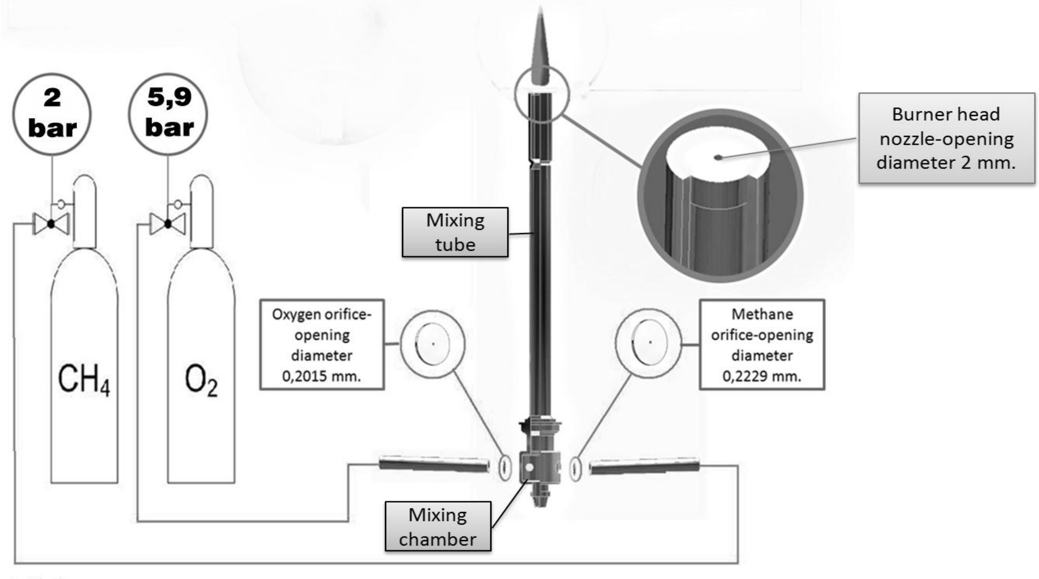

Fig. 8 Scheme of experimental settings.

After setting of all parameters from fig. 8, it was performed experimental ignition. On the next fig. 9 you can see the shape of the flame after setting the calculated parameters and ignition of burner. Is it obvious that the length of the flame is in the desired limit of 100 mm.

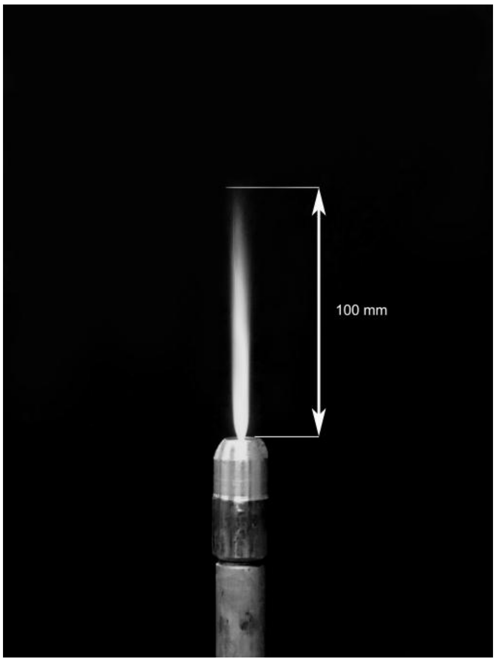

Fig. 9 Blow in burner with calculated parameters.

8 CONCLUSIONS

The aim of this work was the modification of burner, originally used for combustion mixture of stack gas with air to combustion mixture of methane and oxygen. This setting changes was implemented with the calculation of new parameters adjusted by orifices, pressure difference *Δp* and flow velocity V for each gases entering to the mixing chamber of the burner. Subsequently there was recalculated setup of burner head, which was modified from twelve nozzles to one central nozzle with diameter of hole 2 mm. Burning of mixture of methane and oxygen was carried out above the burner to avoid excessive heating of the burner and blow-back.

Another condition that had to be met, was the flame height to 100 mm. It has been experimentally verified; see in fig. 9. The flame height is really in the range up to 100 mm.

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