INTENSIFICATION OF COMBUSTION PROCESS BY FUEL INCREASED PRE - MIXING

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Abstract

Natural gas is one of the most valuable energy sources. One of the potential ways to increase efficiency of gaining energy from natural gas is intensification of the combustion processes. This paper deals with the intensification as technical redesign construction of burner, where we use a simple component like mixer. The primary function of mixer is to improve mixture of natural gas and oxidizer. Three types of flammable mixers of different construction were designed. The proposal itself includes simulations of flow in experimental device. The simulation of flow was focused on mixture velocity and mixture pathlines. The analysis of measurements was focused on comparison of the designed mixers regarding the production of CO and achieved temperatures.

Key words

intensification, combustion, natural gas, mixer

Introduction

As one of the dominant market fuels, natural gas is being increasingly used as a source of heat and electricity due to its primary advantages (easy transport and regulation, combustion with low excess of the combustion air and low rate of particles of the unburned combustible fuel formation). Even though during the last decade, more new technologies emerged on the market, natural gas combustion in a conventional manner keeps a dominant position in relation to this progressive technology. The price of natural gas keeps rising, and it is therefore necessary to find the ways to reduce its consumption while maintaining or increasing its production and product quality (1, 2).

One of the appropriate alternatives for the intensification of combustion processes is the modification of the burner as a technological device, where it is necessary to significantly interfere into the production process (3). Intensification is manifested in particular by:

- achievement of higher combustion temperatures,
- improved combustion of flammable fuel components,
- variation of the concentration of the components in the flue gas produced,
- changed shape of the flame (4, 5).

This article describes the intensification of the combustion of natural gas with air as selected, which is supported by graphical design, simulation applying the ANSYS software, while focusing on the flow velocity in the burner devices. Analysis of the collected results is focused on the temperature achieved along the height of the flame and formation of CO and NO_x for the purpose of evaluating the quality of combustion.

Experimental device

Practical measurements were carried out to evaluate the impact of mixers of pre-mixed fuels on the combustion process, and these were implemented on an experimental device – a simple kinetic burner in combination with a metal combustion chamber (Fig. 1).

Along the height of combustion chamber, other chamber thermocouples were deployed for the location of thermocouples in order to measure the temperature along the height of the flame. To avoid false air sucked into the combustion chamber respectively into the flue, there was a throttle, whose primary task was to maintain pressure in the burner devices.

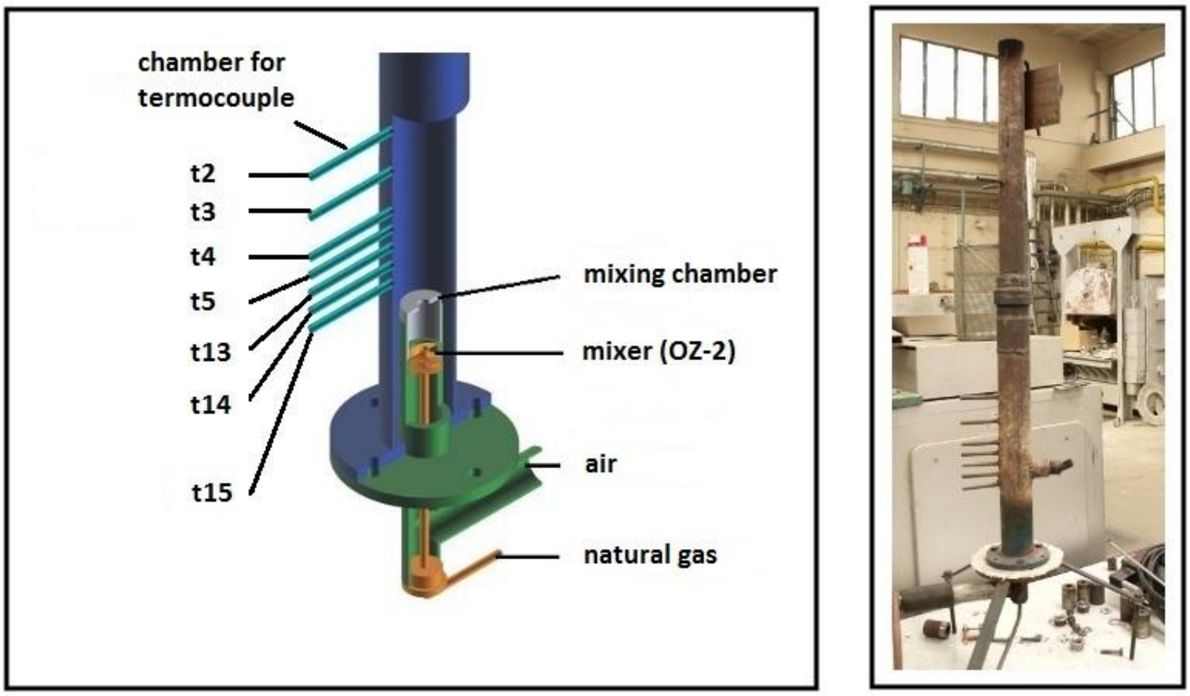

Fig. 1 *Model of an experimental device (left) and a shot of the real experimental device (right)*

Fig. 2 shows a scheme of connectivity of the experimental device. Natural gas was used as fuel and air was used as oxidant. Both gaseous media successively passed through the flow regulator. Besides of the flow regulator, measured was the temperature and pressure of the gaseous media. The device operated under the constant output power of 2 kW.

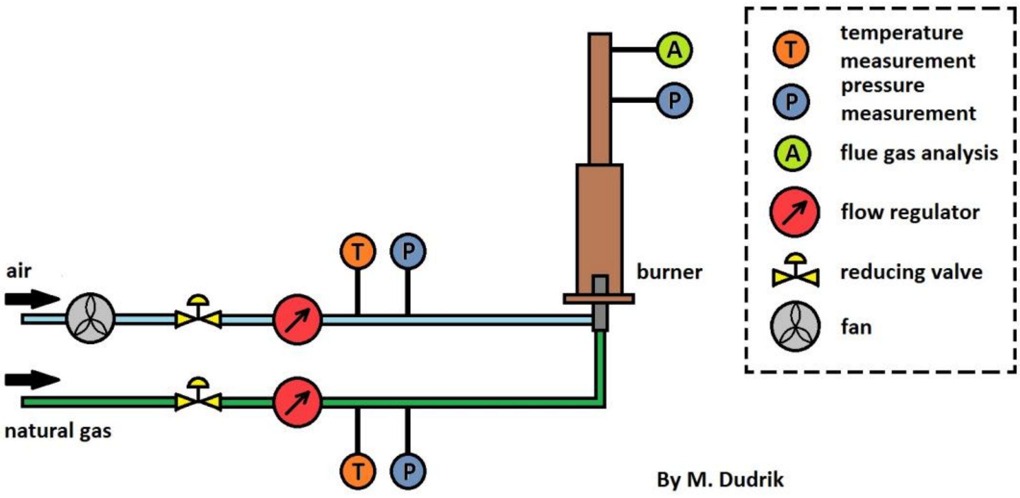

***Fig. 2** Scheme of connectivity of the experimental device*

Pre-mixing of the flammable mixture

Owing to the intensification of combustion processes, the mixers were designed to be used for the flammable mixture (Fig. 3). Their primary task was to increase the mixing of gaseous fuel (in our case natural gas) and oxidant (in this case air).

For the experimental device, three types of mixers were designed, namely OZ-1, OZ-2, and OZ-3. The main difference was in the construction design of the mixers. The design should provide different mixing in the mixing chamber, which should be reflected in the combustion process quality. All three types of mixers were structurally designed so that to be deployed for the supply of natural gas and not to affect the gas stream directly before entering the mixing chamber. Mixers directly affected only the air inflow.

***Fig. 3** Design of graphical models of mixers (upper line) and a shot of manufactured mixers (lower line)*

In OZ-1 type, six combustion air inlet pipes are symmetrically distributed around the central fuel supply. These inlet pipes are directed under an angle of 70° towards the vertical axis of the mixing chamber. In OZ-2 type, there is no direct distortion of the gas stream by the air for combustion. The primary task of mixer OZ-2 is generating the intense swirling effect in the mixing chamber, which should be partially reflected in the shape of the flame in the combustion chamber. The assumption was that the effect of vortex guiding is provided by two spiral tunnels through which the combustion air flows and that consequently leads to entrainment of flow gas by the air stream for combustion.

Design of OZ-3 type is based on the type of construction of OZ-1 and OZ-2 types. This type of the flow distortion represents a combination of direct interference of natural gas with air for combustion and creation of turbulence in the mixing chamber. However, instead of guide spiral tunnels were used guide vanes, which were deflected to the horizontal axis by 15°, which provided a tangential supply of oxidant. With the aim to assess the impact of the mixer upon the combustion process, the measurements were made on an experimental device also without mixer in the burner equipment (type OZ-0).

Simulations of velocities flow and velocities pathlines

The design mixers of flammable mixtures was based on the assumption that the structural design will be sufficient to create a strong mixing of gas and air for combustion in the mixing chamber. In order to verify these assumptions, pathlines were developed by simulation of velocities for the experimental device. Simulations were performed in ANSYS for gas composition shown in Table 1 and the mass flows shown in Table 2.

COMPOSITION OF NATURAL GAS Table 1

CH_4 (%)	C_2H_6 (%)	C_3H_8 (%)	n-C_4H_{10} (%)	Izo-C_4H_{10} (%)	n-C_5H_{12} (%)	Izo-C_5H_{12} (%)	C_6H_{14} (%)	CO_2 (%)	N_2 (%)
96.38	1.73	0.51	0.07	0.08	0.01	0.01	0.03	0.32	0.87

Velocity and velocity nozzles were simulated for an experimental device with a metal combustion chamber, as shown in Fig. 1. During the simulation, the focus was mainly on the flow intensity in the burner device, and therefore the temperature of the gaseous media of 20 °C was considered.

VALUES OF MASS FLOW THAT WERE USED IN SIMULATIONS Table 2

natural gas (kg.s^{-1})	air (kg.s^{-1})
4.31.10^{-5}	7.92.10^{-4}

The simulated speed and velocity nozzle in the experimental device are shown in Fig. 4. All types of proposed mixers achieved the higher velocities compared to the experimental device, in which the mixer of flammable mixture (model OZ-0) was not applied. In case of type OZ-1, achieved were the highest velocities of gaseous media in comparison to the remaining variants of measurements. It reached its maximum at around 6.7 m.s^{-1}. Simulation of speed nozzle confirmed the assumption that the type OZ-1 leads to the intensive distortion of natural gas flow by air for combustion. With the type OZ-2, achieved was strong velocity close to the wall of the mixing chamber. Rendering speed pathlines confirmed that very intense swirling effect occurs in the burner.

With the type OZ-3, reached was the lower velocity of gaseous media flow, which reached its maximum close to the wall of the mixing chamber, just like in case of OZ-type, but with lower values. Pathlines in Fig. 4 pointed out that there should be the intensive turbulence. Among the types compared, the most intense turbulence was formed in the application of OZ-2. In the experimental device without mixer applied in simulated speed nozzle, there is no significant distortion of current gas by oxidizing agent. Supplied oxidant filled the space of the combustion chamber immediately after leaving the mixing chamber.

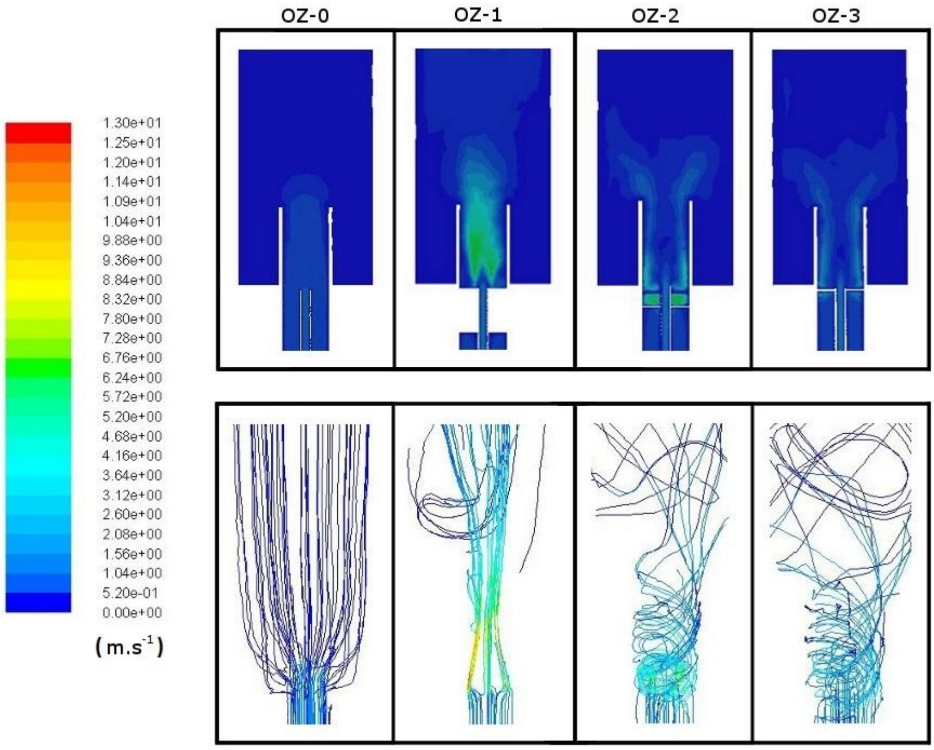

Fig. 4 *Simulated velocity flow in the experimental device (upper line) and simulated velocity pathlines (lower line)*

Discussion

Experiments were designed to measure the temperature along the height of the flame and to analyze the type of the produced gaseous pollutants, especially with focus on CO and NO_x. When measuring temperature, the first measuring point, i.e. t15 thermocouple, was located approximately 20 mm above the mouth of the burner. The second measuring point, i.e. t3 thermocouple was located at the distance of about 200 mm from the mouth of the burner.

When measured without mixing, temperatures above the mouth of the burner achieved around 770 °C and in the middle of the combustion chamber around 760 °C. The highest temperatures were achieved when applying OZ-1mixer, when the thermocouple t15 reached the temperature over 1000 °C and a thermocouple t3 over 850 °C. At these temperatures, the production of CO was relatively high - around 150 ppm. The OZ-2 mixer reached the lowest temperature comparing to other variants of the measurements, due to the take-off points and the enormous production of CO, which exceeded the 5000 ppm. This type thus appeared to be unsuitable for the intensification of the combustion process. The graphical comparison (Fig.5) clearly shows that the most suitable type for the combustion is OZ-3 mixer – from the point of the quality assessment. Even though similar temperatures as with the OZ-0 type were reached, the production of CO remained significantly lower. There was approximately 90% decrease in the concentration of CO in the flue gas in comparison to the alternative where no mixer was used.

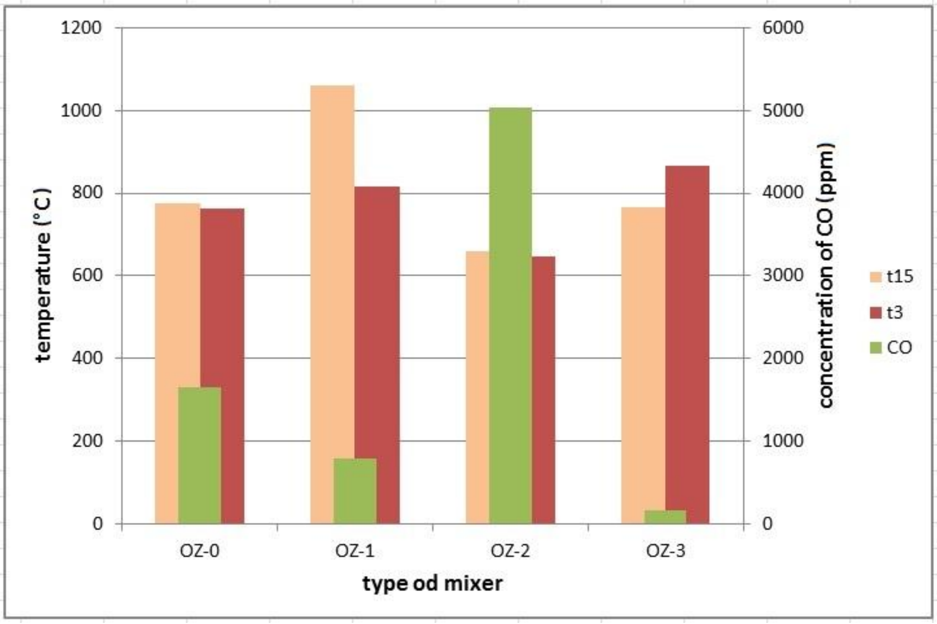

Fig. 5 *Comparison of the reached temperatures and concentration of CO emissions depending on the mixer type*

Given the assumption that the designed mixer of flammable mixture could cause a significant increase of combustion temperatures, the flue gas analysis focused on the concentration of NO_x in the flue gas produced. NO_x formation is influenced mainly by the temperature and holding time at these temperatures. The main components of the NO_x emissions are the thermal oxides of nitrogen arising at the temperatures above 1300 °C (6, 7).

Fig. 6 shows a graphical comparison of concentrations of NO_x in the flue gas observed by the practical measurements with the designed mixers and without mixers. The graphical comparison shows that the most types were without major fluctuations in the concentration of NO_x. For the mixer of OZ-0 type, the concentration of NO_x was about 40 ppm. The most significant concentration was reached with OZ-3 mixer, which was approximately double compared to the OZ-0 type. Such an increase can be justified by the long flame during combustion, thereby increasing the area of high temperatures (Fig. 5).

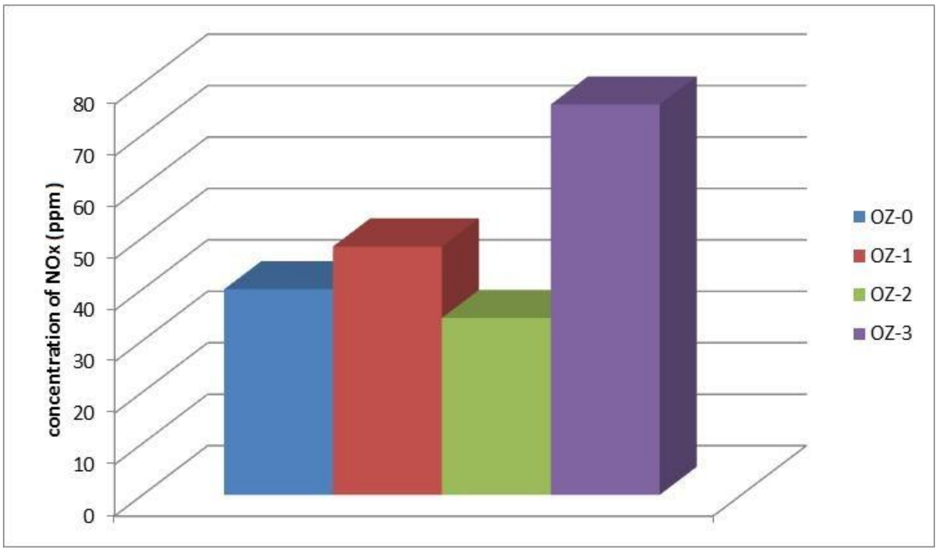

Fig. 6 *Comparison of concentration of NO_x emission in produced flue gas, where the mixer was not used (type OZ-0) and where designed mixers were applied*

Conclusion

The analysis of practical measurements revealed that using a suitable type of mixing can increase combustion temperatures (Fig.5). Based on the comparison of the mixers for flammable mixtures, there was a significant increase in the flame temperature only in the OZ-1type, which was based on the principle of direct current distortions of gas by stream of combustion air. This principle seems to be the most effective way in achieving higher combustion temperatures. With the mixer of OZ-2 type, reached was the lowest temperature among all the tested types and the highest production of CO, which seems to be the least suitable for the intensification of the combustion processes. In type OZ-3, only 90% decrease in the concentration of CO in the flue gas produced occurred, in comparison to the OZ-0 type. Based on these results, it may be deduced, that a combination of direct disruption of current fuel combustion air and creation of intense turbulence in the mixing chamber seems to be the best option for the specific torch.

Combustion of natural gas with air does not generate a temperature high enough to cause a vigorous formation of NO_x. Among all the types tested, significant production of NO_x emissions was reached only when the OZ-3 mixer was used. Significant variation in production is probably caused by producing a longer flame when there is an increase in holding time as the cause of NO_x emissions under high temperatures. Acquired results indicate that by the intensification of the combustion process by applying the mixers, it is possible to increase the efficiency of the technology unit, to increase the production, and respectively to improve the quality of the product itself.

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References:

1. FÍK, J. 2006. *Natural gas*. ISBN 80-86028-22-4
2. VARGA, A. 1999. *Heat technology in metallurgy*. Košice. ISBN 80-7099-449-5
3. FÍK, J. 1998. *Combustion of gaseous fuels and gas burners*. ISBN 80-86176-01-0
4. BAUKAL, CHARLES E. 1998. *Oxygen - enhanced combustion*. ISBN 0-8493-1695-2

5. KIZEK, J., LAZIČ , L. 1999. Simulation method for optimization of a mixture of fuel gases. *Metalurgija*, **38**(2), pp. 109-113. ISSN 0543-5846
6. WILK, R. K. 2002. *Low-emission combustion*. Gliwice. ISBN 83-7335-058-6. Gliwice.
7. KIZEK, J., ZSIGRAIOVÁ, Z. 2001. Combustion of gaseous fuels with high content of inert. *Metalurgija*, **40**(4), pp. 233-236. ISSN 0543-5846
8. ROZPONDEK, M., WNEK, M. 2011. Energy and environmental studies of gas burners. *Acta Metallurgica Slovaca Conference*, **2**(1), pp. 189-194. ISSN 1338-1660
9. GIL, S. 2011. Modeling of the nitrogen oxides emission during pressurized char combustion. *Acta Metallurgica Slovaca Conference*, **2**(1), pp. 16-23. ISSN 1338-1660
10. SKOK, P., RIMÁR, M., ŠALAMON, R. 1996. Combustion of gaseous fuels with regard to carbon monoxide emission limit. *Energetika*, **46**(4), pp. 127-129. ISSN 0375-8842

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