

EXPERIMENTAL OPTIMIZATION OF LOW POWER ATMOSPHERIC BURNER

Aleksandar Milivojević*¹, Miroljub Adžić¹, Vuk Adžić¹, Mirjana Stamenić¹

Faculty of Mechanical Engineering, University of Belgrade

Abstract: The aim of this experimental research is to confirm the correctness of the proposed methodology for optimizing atmospheric gas burner. Also, the burner will be tested in real conditions. The object of this experimental optimization is a typical modern atmospheric gas burner for households (required heat output for average households ranges from 8 to 12 kW) to which the proposed methodology will be applied in order to optimize its design characteristics and performance with a goal to obtain energy efficient and an environmentally friendly device.

Keywords: experimental optimization, atmospheric burner, energy efficiency, environmentally friendly device.

1. INTRODUCTION

Extensive and very intensive experimental research was conducted, which includes the diameter of the burner fuel nozzle (d_{ml}), the distance of the nozzle outlet from the burner inlet (Δh_{ml}), the area of the flame openings (number of flame openings), NO_x emissions, CO emissions, the diameter of the cylindrical mixer burner (mixer neck), type of gaseous fuel used, change in power range, the primary coefficient of excess air as well as investigation of the burner installed in a selected gas device performance. Modern atmospheric burners, which have been constructed for higher thermal power (of the order of 10 kW) compared to conventional atmospheric burners (of the order of 2 kW), have retained the Venturi system of mixing fuel and air, and designed flame ports not to form individual flames, as is often the case with classical systems, but more or less to form one global flame. In order to confirm the operating characteristics of the optimized burner in real conditions, it was necessary to choose a gas device that is used in an average household. The use of gaseous fuel for heating purposes is increasingly suppressing the use of solid and liquid fuels, especially when it comes to individual boiler rooms related to households. It is important to emphasize that as part of

* Corresponding author e-mail: amilivojevic@mas.bg.ac.rs

encouraging the development of the domestic economy, it was decided that the manufacturer of the gas appliance in question be a representative of the domestic gas appliance industry. The gas heater Alfa 9, manufactured by domestic Alfa-Plam Vranje company, was chosen as a representative gas device, in which the optimized gas burner will be tested at real operating conditions.

2. EXPERIMENTAL INSTALLATION

The independent influencing parameters that were optimized are: nozzle diameter, distance of the nozzle from the entrance of the mixer, diameter of the Venturi mixer, area and shape of the flame ports. During the tests, different types of fuel were used: LPG (a commercial mixture of propane and butane), natural gas and biogas. In order to realize the experimental tests carried out in this work, it was necessary to form an experimental installation. Then a reference or starting point was determined by determining the performance of the Alfa 9 gas heater, in which the newly obtained burner should be installed, equipped with its original burner, with the aim of determining the initial level of performance of the selected gas control device.

3. DETERMINATION OF NOZZLE DIAMETER

Based on the calculation of atmospheric burners, as well as the analysis of the mathematical model of the burner and the available pressure in the installation for different gaseous fuels (LPG, natural gas, biogas), the diameter of the nozzle (d_{ml}) was calculated for the different types of gaseous fuel that were used during the test: $d_{ml} = 2,25$ mm for LPG, $d_{ml} = 2,5$ mm for natural gas, $d_{ml} = 4,5$ mm for biogas.

4. DETERMINATION OF THE DISTANCE OF THE NOZZLE OUTLET FROM THE BURNER MIXER INLET

The value of the primary excess air coefficient λ' affects the emission of combustion products and efficiency, which is shown in diagram 1, which was obtained on the basis of numerical research.

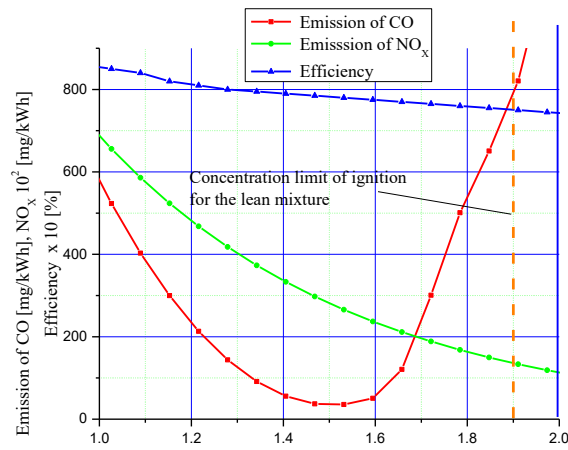


Diagram 1. Dependence of co and NO_x emissions as well as the efficiency from the primary excess air coefficient λ'

As can be concluded from diagram 1, in order to satisfy the optimization criteria, of emissions limits of 50 mg/kWh, the value of the primary excess air coefficient λ' should range from 1.4 to 1.54. The aim of this test was to determine the influence of the distance from the nozzle outlet to the burner mixer inlet Δh_{ml} , on λ' . Namely, the idea was to determine the change in the value of λ' when Δh_{ml} increases from 0 to a certain value, that is, to determine whether λ' increases or decreases. The optimized parameter Δh_{ml} and its influence on the performance of the burner, specifically on λ' , can only be determined experimentally. The layout of the experimental installation that was used is given in Figure 1. Namely, in this occasion, in order to avoid explosive mixture of fuel and air, CO₂ was used instead of fuel, since it has the same molar mass, the same density as propane C₃H₈, while at the exit from the mixer, the content of CO₂ in the achieved mixture of CO₂ + air have been measured, using a gas analyzer, and based on that, the primary air coefficient was calculated. The flow of CO₂ is determined to model the nominal thermal powers of 100%, 66% and 33%, in relation to the full capacity of the given burner. In each of the mentioned tests, Δh_{ml} was varied.

From the resulting diagram, it is clearly seen that the primary coefficient of excess air λ' decreases with the increase in the distance from the nozzle exit to the burner mixer inlet Δh_{ml} , which was expected considering the fuel jet expansion angle. It is also noticeable that there is no significant difference in the results when varying the fuel flow, that is, the thermal power of the burner. Also, diagram 2 shows that the maximum value for λ' is obtained when positioning the nozzle at the very entrance to the mixer. As the goal is to obtain the value of λ' in the interval 1.4 – 1.54, which can be seen in diagram 1, it can be concluded that in order to reach the optimal operating conditions the distance $\Delta h_{ml} = 0$ is chosen.

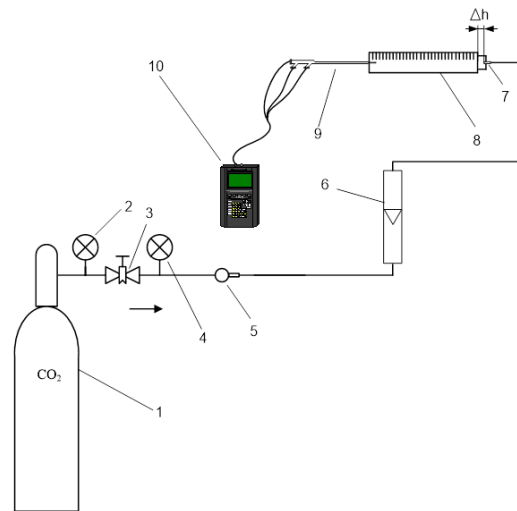


Figure 1. Schematic representation of the experimental installation

1 – CO₂ gas tank, 2 – manometer, 3 – regulation valve, 4 – manometer, 5 – pressure regulator, 6 – rotameter, 7 – nozzle $d_{ml} = 2,5$ [mm], 8 – burner, 9 – gas analyzer probe, 10 – gas analyzer TESTO 350 XL

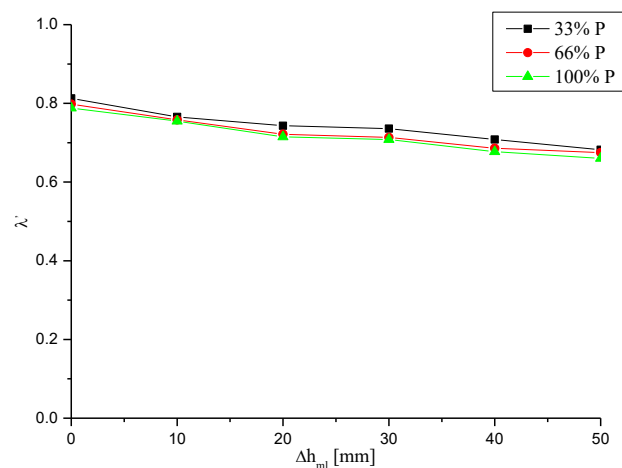


Diagram 2. Dependence of λ' – the primary air coefficient on Δh_{ml}

5. PRIMARY COEFFICIENT OF EXCESS AIR (λ') AS A FUNCTION OF COMBUSTION CHAMBER PRESSURE DROP

The gas burner - combustion chamber system has certain pressure drop, i.e. pressure losses, caused by the geometry of the burner and the combustion chamber. The increase of pressure drop directly affects the amount of ejected primary air, i.e., the decrease of the primary air coefficient λ' , which is reflected in the combustion process. The results of the effect of the pressure drop in the combustion chamber on the value of the primary coefficient of excess air are shown in diagram 3.

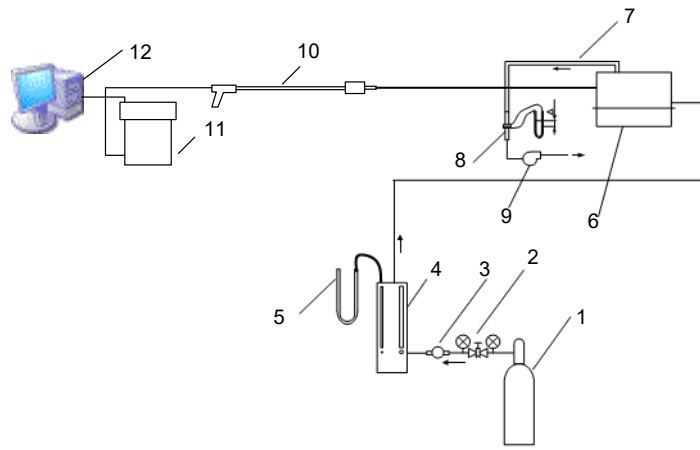


Figure 2. Schematic representation of the experimental installation

1 - CO₂ gas tank, 2 - regulation valve, 3 - pressure regulator, 4 - rotameter, 5 - manometer with U-tube, 6 - combustion chamber with burner, 7 - line for mixture of CO₂ and air, 8 - measuring aperture, 9 - fan, 10 - gas analyzer probe, 11 - gas analyzer TESTO 360, 12 - computer.

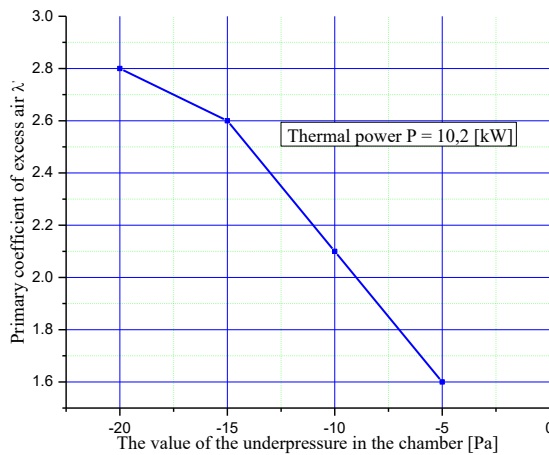


Diagram 3. Primary coefficient of excess air λ' as a function of underpressure in the combustion chamber

From the results shown (diagram 3), it can be seen that with a decrease in the underpressure in the combustion chamber (the assumption is that this decrease in pressure causes an increase in resistance in the burner - combustion chamber system) there is a decrease in the value of the primary coefficient of excess air λ' .

6. DETERMINING THE PERFORMANCE OF THE ALFA 9 GAS HEATER

Since the Alfa 9 gas heater was chosen as the control device for testing the operating characteristics of the optimized burner in real operating conditions, it was necessary to determine the operating characteristics of this gas device in its original version. The experimental installation shown

in Figure 3 gave the possibility of testing the performance of the gas device when using different types of fuel (LPG, natural gas, biogas).

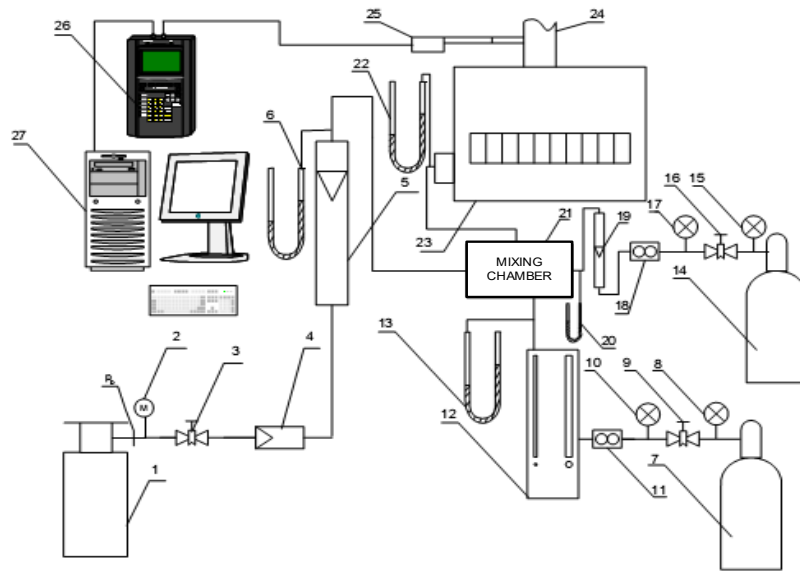


Figure 3. Schematic representation of the experimental installation

1 - gas tank with $C_3H_8 + C_4H_{10}$, 2 - manometer, 3 - regulation valve, 4 - pressure regulator, 5 - rotameter, 6 - manometer with U-tube, 7 - gas tank with CH_4 , 8 - manometer, 9 - regulation valve, 10 - manometer, 11 - pressure regulator, 12 - rotameter, 13 - manometer with U-tube, 14 - gas tank with CO_2 , 15 - manometer, 16 - regulation valve, 17 - manometer, 18 - pressure regulator, 19 - rotameter, 20 - manometer with U-tube, 21 - mixing chamber, 22 - manometer with U-tube, 23 - gas heater Alfa 9, 24 - exhaust of combustion products, 25 - gas analyzer probe, 26 - gas analyzer, 27 - computer.

7. TESTING OF THE REFERENCE BURNER INTEGRATED IN THE ALFA 9 GAS HEATER

The chosen reference burner was integrated into the Alfa 9 gas heater in order to test the performance of this burner in the gas device for which it is intended, and get the reference performance parameters of the heater. The fuel used during the test was LPG, and the heat output of the burner was varied in the range from 33% (3.4 kW) to 100% (10.2 kW). The emission of combustion products (CO and NO_x) was measured. During the tests of the reference burner, the obtained results were averaged for different thermal powers and shown in diagrams 4 to 6.

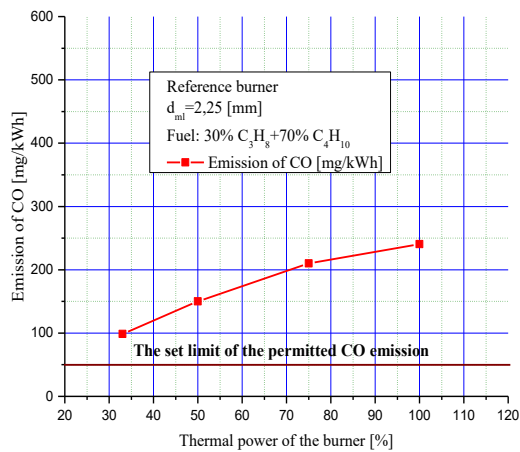


Diagram 4.

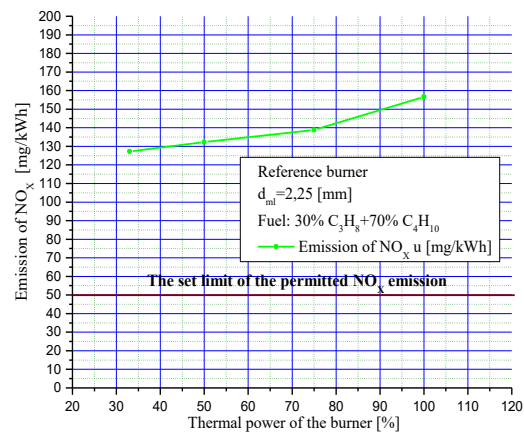
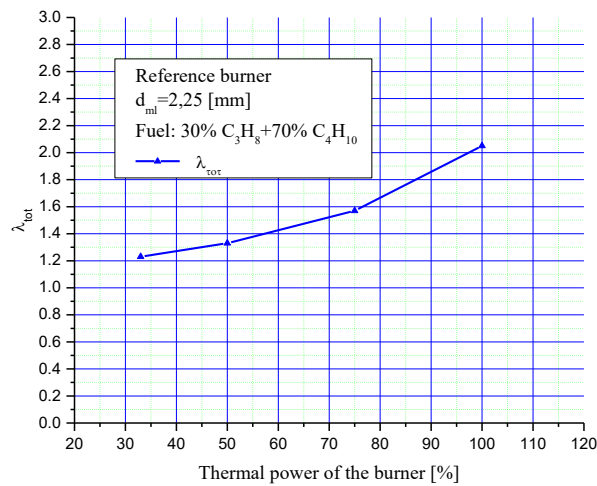


Diagram 5.



Dijagram 6.

As can be seen, in diagrams 4 to 6., the emissions of CO, NO_x, and total air coefficient λ_{tot} , increase with the increase of thermal power.

8. DESIGN IMPROVEMENTS OF THE REFERENCE BURNER

For the initial phase of testing, the reference burner manufactured by BCT was selected as the first phase of the burner, which should meet the required performance specified in the task of this work. It is an injector burner with a classic Venturi mixer, with slit-shaped flame openings arranged in three rows with a nominal power of 10.2 [kW]. The burner is multi-fuel, intended for operation with liquefied petroleum gas, natural gas and biogas.

In order to increase the primary air coefficient, the burner flame ports area was increased. It was found that that the increase by 1,07 times, satisfies the goal of emission limits for the appliance.

9. EXPERIMENTAL CONFIRMATION OF THE BURNER OPTIMIZATION METHODOLOGY

In order to determine the performance of the tested gas device and burner under the conditions of using fuel of different composition and quality, different thermal powers and coefficients of excess air, the following parameters were varied: types of fuel (LPG - 30% C₃H₈, 70% C₄H₁₀, $d_{ml} = 2.25$ mm; technical methane - 99.5% CH₄, 0.5% N₂, $d_{ml} = 2.5$ mm; natural gas - 79.6% CH₄, 0.4% N₂, 20% CO₂, $d_{ml} = 2.5$ mm; biogas - 59, 7 % CH₄, 0.3 % N₂, 40 % CO₂, $d_{ml} = 4.5$ mm), operating range of the gas device or burner (in terms of power), primary coefficient of excess air, pressure drop in the combustion chamber. The main parameters that were monitored and measured during these tests were: flame shape and stability, CO and NO_x emissions, coefficient of λ_{tot} .

10. THE INFLUENCE OF DIFFERENT TYPES OF GASEOUS FUELS ON BURNER OPERATION

The quality of the fuel is a very important parameter, especially its influence on the emission during the operation of low-emission atmospheric burners. In the experiments conducted during this test, the influence of the type of gaseous fuel on flame stability, the dynamic power range of the optimized burner and the emission of combustion products (CO and NO_x) were checked. Two series of measurements were carried out, each with a different type of gaseous fuel. In the first series of measurements, optimized burner 1 and LPG (30% C₃H₈, 70% C₄H₁₀) were used. In the second series of measurements, optimized burner 1 and technical methane (99.5 % CH₄, 0.5 % N₂), natural gas (79.6 % CH₄, 0.4 % N₂, 20 % CO₂) and biogas (59.7% CH₄, 0.3% N₂, 40% CO₂). In both cases, the heat power was varied from 33% (3.4 kW) to 100% (10.2 kW).

11. ANALYSIS OF RESULTS

Based on the set goals, during the implementation of the optimization methodology of the subject atmospheric burner, in terms of stability of operation, dynamic range of operation (1:3), emissions (CO emission < 50 mg/kWh, NO_x emission < 50 mg/kWh), numerous experimental tests, described in previous chapters. For the purposes of the final consideration, which should provide an answer to the tasks set in this work, the test results were taken with the following adopted parameters: nozzle diameter $d_{ml} = 2.25$ mm, fuel - LPG (propane C₃H₈ 30%, butane C₄H₁₀ 70%), secondary air vents fully open, tested burners (selected reference burner, optimized burner 1) were integrated into

the ALFA 9 gas heater, the thermal power of the device varied from 33% ($P = 3.4$ kW) to 100% ($P = 10.2$ kW) according to the required dynamic operating range of 1:3.

12. REFERENCE BURNER

As a starting point for optimization in real operating conditions, the reference burner was integrated into the control gas device Alfa 9 and tested. During the test of the reference burner, for previously defined test conditions, NO_x and CO emissions were obtained and averaged for different thermal powers and shown diagram 7.

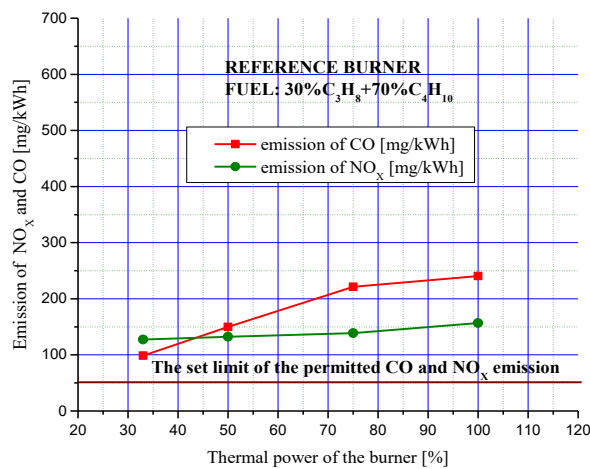


Diagram 7.

The obtained results of the experimental tests of the reference burner show that the measured NO_x and CO emissions exceed the prescribed limit of 50 [mg/kWh] over the entire dynamic range of operation (1:3), while the measured total coefficient of excess air (λ_{tot}) ranges from 1.23 to 2.05. Such test results indicated the need for appropriate reconstructive interventions on the chosen reference burner in order to satisfy the emission limits.

13. OPTIMIZED BURNER 1

In order to improve the results obtained during the test of the reference burner, since the burner did not meet the set requirements, the following reconstruction procedures were performed on the reference burner in accordance with the performed numerical and experimental tests:

- The initial arrangement of flame openings was replaced by a new one - three rows of equal openings of the order of 10 x 1 mm in size, with an increase in the distance between the rows of flame openings by 1.2 times.

- The length of the burner has been increased.
- The initial area of the flame holes increased 1.07 times.

It can be seen that with an increase in the A_{PL}/A_{PLO} ratio (A_{PLO} – initial area of the flame openings, A_{PL} – current area of the flame openings) CO and NO_x emissions decrease. Namely, with the increase in the area of the flame ports, the ratio A_{PLO}/A_{PL} increases resulting in the increase of the coefficient of excess air λ' .

The test of the optimized burner 1 was performed under the same conditions under which the test of the reference burner was performed. The obtained NO_x and CO emission results, during the test of the optimized burner 1, are also averaged for different thermal powers and shown on the diagram 8.

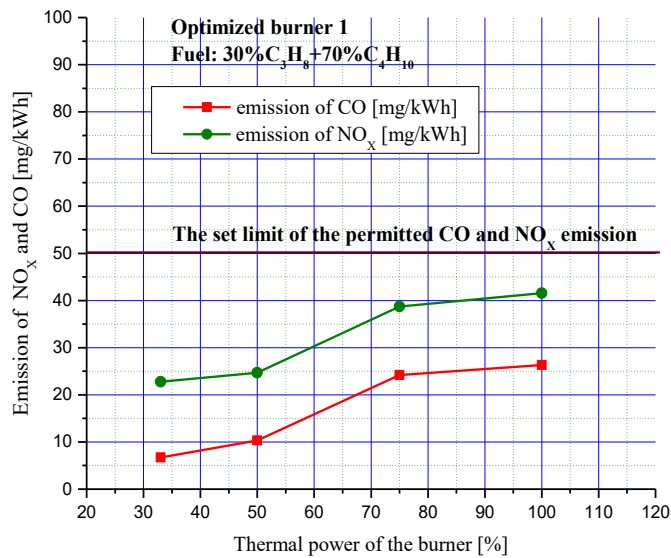


Diagram 8.

During the testing of the optimized burner 1, the results obtained show that the measured emissions of NO_x and CO are below the set limit emission of 50 [mg/kWh], over the entire dynamic range of operation (1:3), which means that the requirements regarding the permitted emission of harmful combustion products are and dynamic range of operation, fully satisfied. From the results shown, it can be clearly concluded that the type of burner that fully satisfied the set tasks is the optimized burner 1.

14. THE INFLUENCE OF DIFFERENT TYPES OF GASEOUS FUEL ON THE PERFORMANCE OF THE OPTIMIZED BURNER

One of the tasks of this work was the multi-fuel efficiency of the optimized burner. Regarding the consumption of gaseous energy sources in Serbia, natural gas is used, both domestic and imported, then liquid petroleum gas, and since one of the primary directions of energy development is the

application of renewable energy sources, biogas (as a representative of gaseous fuels within renewable energy sources) and its application certainly occupies an important place in energy and the development of gas devices. The natural gas in Serbia has a variable quality depending on sources and time. This is reflected in the composition of the gas, which can change significantly in a short time interval. Changes in the quality of natural gas inevitably lead to changes in many of its characteristics, which directly affects the combustion process and the operation of the burner. Sudden changes in fuel quality can cause unstable operation of the burner, blowing-out or flame flashback. The injector performance of an atmospheric burner is particularly sensitive to fuel quality because of the limited possibilities of regulation than burners with forced air supply. In order to investigate the changes of burner performance that occur due to the quality (composition) of natural gas, a number of thermochemical and physical properties of gaseous fuel were varied depending on to model the compositions.

15. RESULTS AND CONCLUSION OF THE EXPERIMENTAL TEST

Because the results, gathered during testing with a commercial mixture of propane and butane, the optimized burner 1, fully satisfied the tasks set before the optimization methodology performed in this work, and that one of the important tasks of optimizing this burner is multi-fuel *capability*, that is, the operation of the burner in the prescribed operating modes when using different type of gaseous fuel. The optimized burner 1 was experimentally tested with the following types of gaseous fuels: methane (99.5 % CH₄, 0.5 % N₂), natural gas (79.6 % CH₄, 0.4 % N₂, 20 % CO₂), biogas (59.7% CH₄, 0.3% N₂, 40% CO₂). The results of these tests are shown in diagram 9.

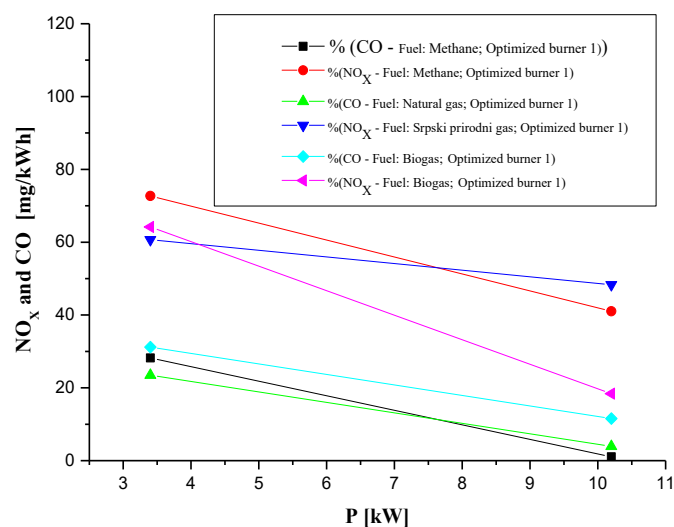


Diagram 9. Emissions for different types of gaseous fuel and optimized burner 1

Diagram 9 clearly shows that the CO emission does not exceed the limit value of 50 [mg/kWh] over the entire dynamic range of operation, while the NO_x emission is slightly higher than the limit value at lower heat powers. This was the consequence of the occurrence of sound instabilities when using these lower calorific value gaseous fuel in the range of thermal power from 30% to 75%. Solving the problem of sound instability during the operation of the optimized burner in the combustion chamber of the reference gas device was not the subject of the optimization methodology adopted and applied in this work. Nevertheless, the results shown in diagram 9 show that at the maximum thermal power of 10.2 [kW], the optimized burner 1 fully meets the requirements set during the optimization of this burner. It can be concluded that performed changes of burner design, as its optimization has been successfully completed.

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