EVALUATION OF THE EFFICIENCY OF THE INTERNAL COMBUSTION ENGINE POWERED BY SYNGAS

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Abstract. In the article evaluation of the efficiency of the internal combustion engine powered by syngas was presented. Eleven tests on the special preparing test station was carried out. The tests were performed for a synthetic gas mixtures characteristic for syngas (ie. hydrogen, carbon mono and dioxide, methane), which is produces by biomass gasification process. The results of the tests allowed to assessment of the parameters characterizing the engine powered by gas fuel (syngas) regarding to its efficiency and ecological aspects.
Keywords: syngas, internal combustion engine, alternative fuel, exhaust emission, ecological engine.

1. Introduction:

Internal combustion engines are still the most common engines used on our roads. But it is supposed that fossil fuels have a short future due to limited resources and they are also a net source of green house gases and other toxic air pollutants. For these reasons, researches all over the world are working on alternative fuels. By this time, a lot of various alternative fuels have been developed, such as various type of vegetable oils, alcohols (ex. bio-ethanol, glycerol), biodiesel, hydrogen (fuel cell), etc. [1, 2].

One of the proposals of alternative fuels could be gas produced in biomass gasification process [3]. In that reaction gaseous mixture of hydrogen, carbon mono- and dioxide, methane and oxygen is produced. That mixture is called SNG (*Substitute Natural Gas*) [4, 5]. In addition in syngas a lot of by-products are formed such as tar, particulate matter, light hydrocarbons, sulfur oxides, chlorine compounds and nitrogen compounds like nitrogen oxides or ammonia [6]. So, before supplying the combustion engine, it is necessary to provide syngas conditioning process.

Depending on the gaseous mixture composition in syngas (especially methane, hydrogen and carbon monoxide concentration), efficiency of the engine could be different. In this paper evaluation of the efficiency of the internal combustion engine powered by syngas (in various composition) was presented. For these tests, syngas have been produced of synthetic gases in laboratory conditions.

2. The test station:

The test station (engine test bed) was complete for evaluating of the efficiency of the internal combustion engine powered by syngas. The first concept of the test station was made in December 2014 and after preliminary tests it was modernized. Initial analysis allowed the precise selection type of engine, engine regulations and develop an algorithm of engine control depending on various composition of gaseous fuel. The test station was made on the basis of power generator PRAMAC S12000 equipped in a spark ignition engine Honda GX630 (see figure 1). In table 1 the technical parameters of Honda GX 630 engine are presented.

Table 1. Technical parameters of Honda GX 630 engine

Parameter	Value
Model	GX 630 20,8 KM
Engine type	four-stroke, two-cylinder, cooled with air
Type of cylinder	Steel made, V 90, OHV
Type of crankshaft	horizontal
Cylinder capacity	688 cm^3
Diameter x stroke	78 x 72 mm
Compression ratio	9,3:1
Maximum power	15,5 kW (20,8 HP)/3500 rpm

Power handling	10,5 kW (14,1 HP)/3000 rpm
Maximum torque	48,3 Nm / 4,93 Kgm / 2500 rpm

Figure 1. Generator PRAMAC S12000 with Honda GX 630 engine

For generator application in the researches, appropriate measurement and control apparatus was required. The internal combustion engine has been adapted to gas fuel supplying by author’s design tube mixer, evaporator BRC AT90P and shut-off valve application. Evaporator, controlled by underpressure, allowed to adjust the composition of the fuel-air mixture for methane. In figure 2 the of the test station was presented.

The system, used for preparing gas mixture, was completed of four gas cylinders, each with a water capacity of 50 litters, containing the pure gases, hydrogen (H_2) with a purity of 5.0, methane (CH_4) with a purity of 2.5, carbon dioxide (CO_2) with a purity of 4.5 and carbon monoxide (CO) with a purity of 1.8 and a gas pressure regulator. Gas pressure was regulated with two two-stage gas reducers, reducing gas in the pressure range of 0 to 4 bar, to allow stabilization of the gas pressure regardless to the gas flow. After reducing the pressure of the gas flows through float rotameters. For each of gas two rotameters were applied to perform precise measurements. Rotameters were provided with control valve for changing the volumetric fraction of a gas. Synthetic gases, known pressure and flow rate, were directed to special cylindrical and closed mixer where homogeneous gas mixture with required composition was created.

Additionally, the test station was equipped with system used for measuring weighting fuel consumption which consisted of:

- fuel tank
- measuring balance Radwag WPE 4000
- measuring flask
- fuel lines.

As a fuel tank the special vessel with the power generator was used. The vessel was installed with the other elements of gas and measuring installation on a mobile rack. A fuel tank was placed at a certain height. It caused that there was no need to use fuel pomp. The fuel from the main tank flowed by gravity through a shut-off valve flask placed on an analytical balance and next, flowed into internal combustion engine. The measurement consisted of a reading of the mass of fuel within a specified time interval. It was very important not to allow into contact between fuel lines and the flask or analytical balance.

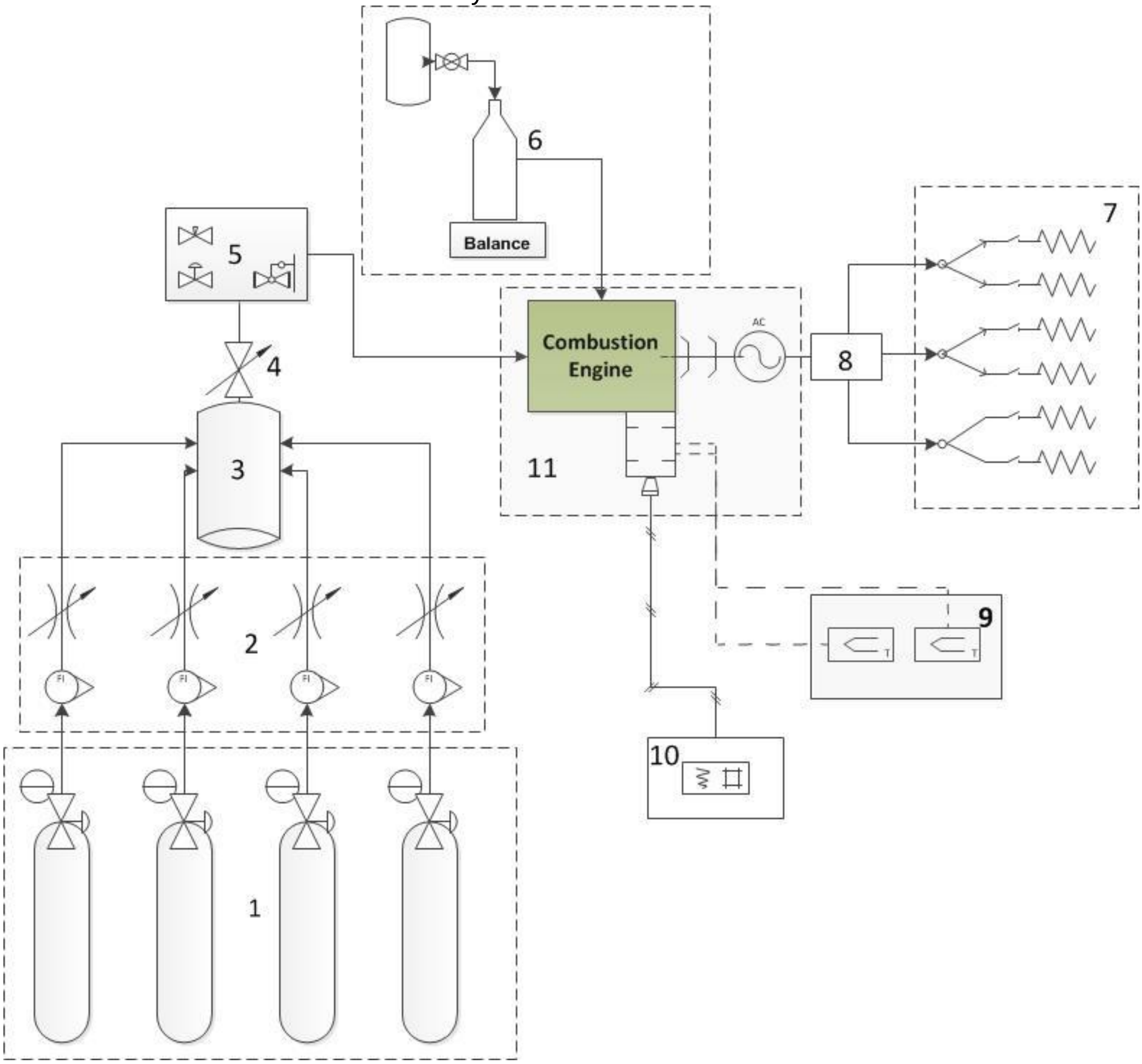

Figure 2. Scheme of the test station: 1 – gas cylinders with reducers, 2 – table of rotates and control valves, 3 – gas mixer, 4 – shut-off valve of the evaporator, 5 – evaporator, 6 – system of liquid fuels consumption measurement, 7 – system of generator loading, 8 – electrical values measuring set, 9 temperature measuring system, 10 – exhaust gas analyser, 11 – power generator

Engine loading system was set of electric heaters with power of 3 of 3 x 1,5 kW and 3x 2 kW which enables charging unit in five working points. Reading the generated power and frequency (rotation speed) was carried out by the meter network parameters using.

The gas temperature sensors were installed in exhaust system (thermocouple type K) for each of the cylinders. Additionally, the fumes analyzer Mexa 584L was connected.For this test station preliminary studies was made.

It was found necessary to modify the test station after carrying out the preliminary tests. The most important test station was changed included:

- installation of control system of injection angle advance
- modification of cooling system
- thermal isolation of the exhaust system

The control system was set of engine controller EMU (EMU Master), cogwheel placed on the crankshaft, shaft position sensor and individual ignition coil (see figure 3). Application of the engine controller allowed integrated all of previously used sensors into one measuring system. The adapter was installed instead of ventilator. That allows installation of cogwheel and special board for shaft position sensor and encoder.

Figure 3. Engine controller EMU installed into a test station

Due to the necessity of measuring the position of the crankshaft, serial cooling system was abandoned. Instead axial ventilator was installed. The engine cover was modified too. Changes in cooling system construction extracted using additional thermal isolation of exhaust system with special height temperature bandage.

3. The experiment:

In the experiment eleven gas mixtures was tested in terms of exhaust emission and correctness of engine's performance. To exhaust emission measurements analyzer Mexa 584L was used. All test fuels with various gas composition used for the engine supply are listed in table 2 and graphically presented in figure 4.

Table 2. Samples of gas composition for engine supply

No.\gas	CO_2	CO	CH_4	H_2
1	1%	35%	10%	53%
2	2%	38%	10%	50%
3	3%	37%	12%	48%
4	4%	39%	14%	43%
5	2%	38%	11%	49%
6	3%	42%	15%	39%
7	6%	28%	37%	28%
8	8%	39%	38%	14%
9	4%	46%	36%	14%
10	4%	45%	24%	27%
11	2%	56%	27%	15%

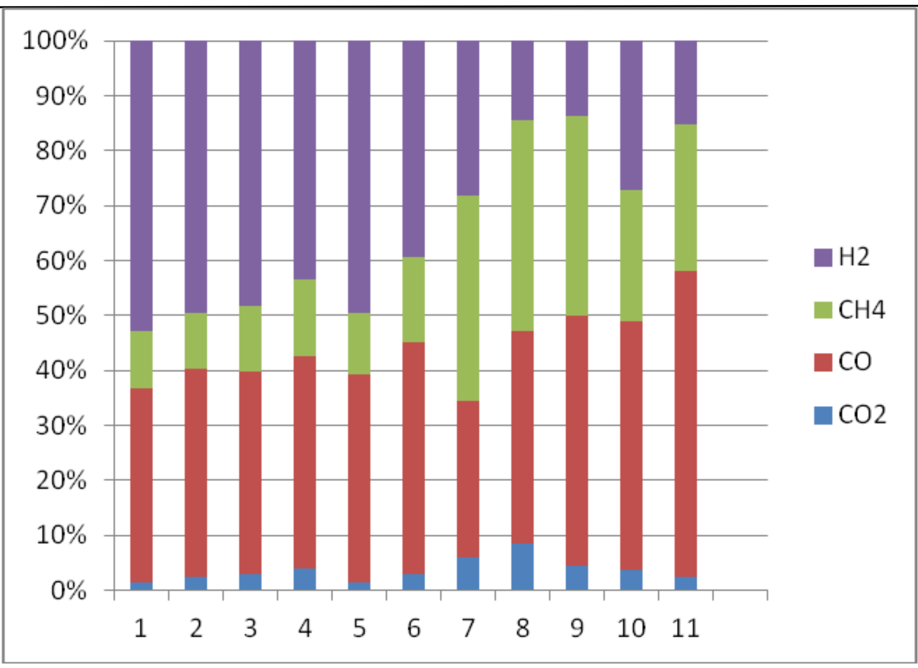

Figure 4. Test gases composition

According to assumptions presented in previous section the tests was carried out at the point with a minimum specific fuel consumption. The system was loaded a constant charge which amounted 6 kW. Every starting the engine was performed with methane.

4. Results and discussion:

Carried out the tests allowed to obtain the information about the following parameters: exhaust temperature, oxygen content in the exhausts, achieved engine power, hourly and specified fuel consumption, rotation speed, torque and concentration of exhaust compounds such as CO, CO_2, HC, NO. Based on that information, evaluation of the engine working in terms of efficiency and ecology of engine (exhaust emission) during combustion gas mixture with a various qualitative composition was available. In addition, for every gas mixture calorific value was calculated. To assessment of correctness of engine working various of analyzed parameters was compared.

In figure 5 exhaust temperature with oxygen content was compared. As it is presented at the graph, the change of oxygen content in exhaust influences the temperature of them. With higher oxygen content in the exhaust, the temperature of them decreases.

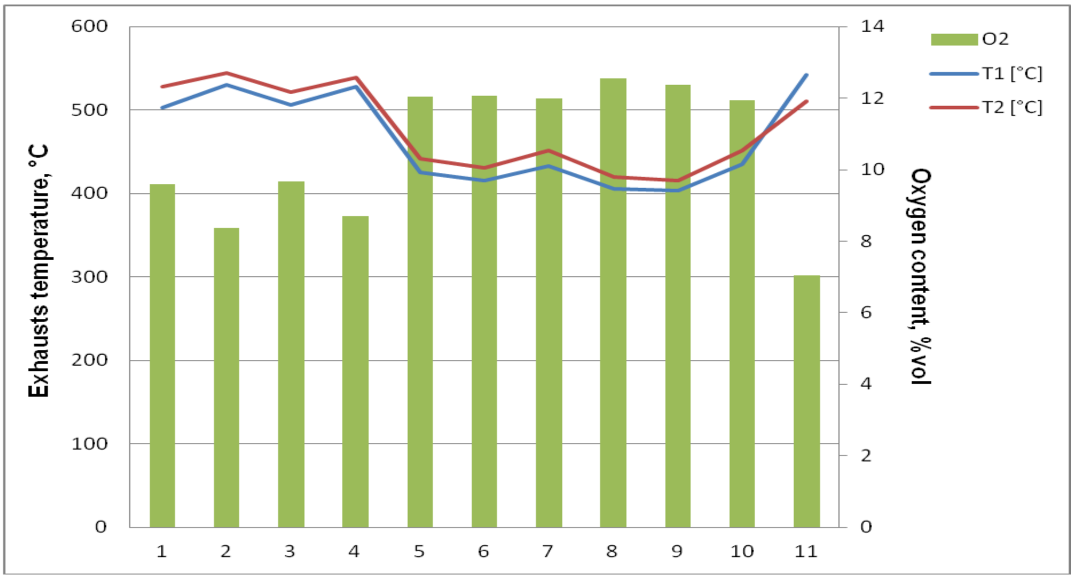

Figure 5. Exhaust temperature if function of oxygen content

Discussing the rotation speed, oxygen content in exhaust and calorific value for various gas mixtures, it appears that in low value of oxygen emission, rotation speed is growing (see figure 6). In mixture consisted of 2% of CO_2, 56% of CO, 27% of CH_4 and 15% of H_2 (mixture 11), the highest value of rotation speed is achieved, while the concentration of O_2 is the lowest. It is hard to define if calorific value impact on remaining parameters.

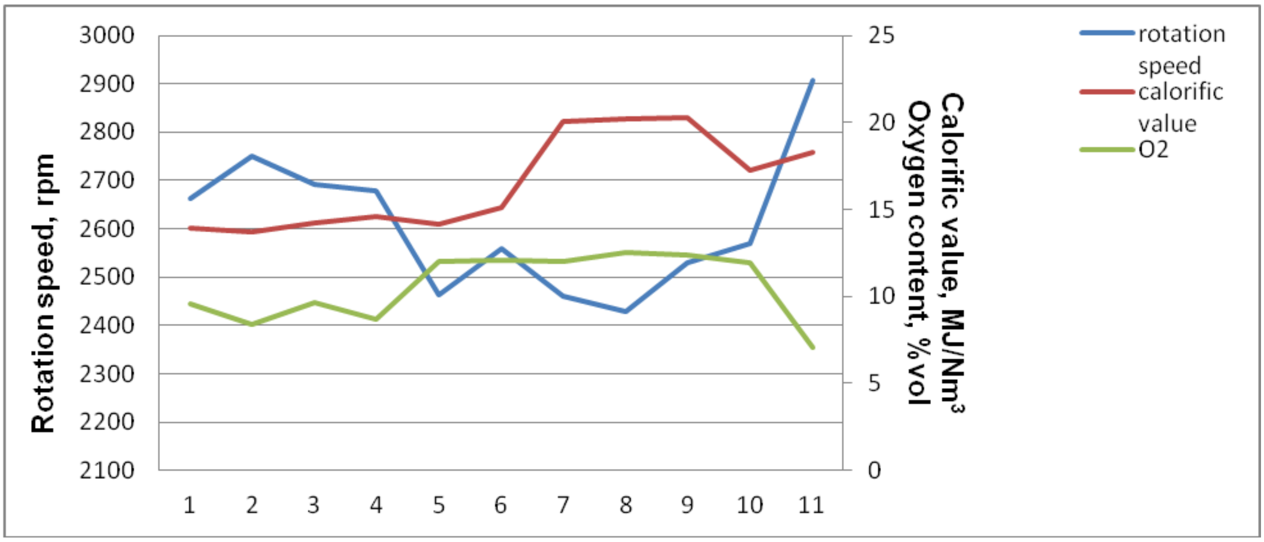

Figure 6. Rotation speed, oxygen emission and calorific value in function of gaseous fuel compositions

As it is shown in figure 7, fuel consumption is higher in mixtures with high calorific value (which is especially visible in mixtures 7-9). It can be also observed that with increasing of engine power, the fuel consumption is lower.

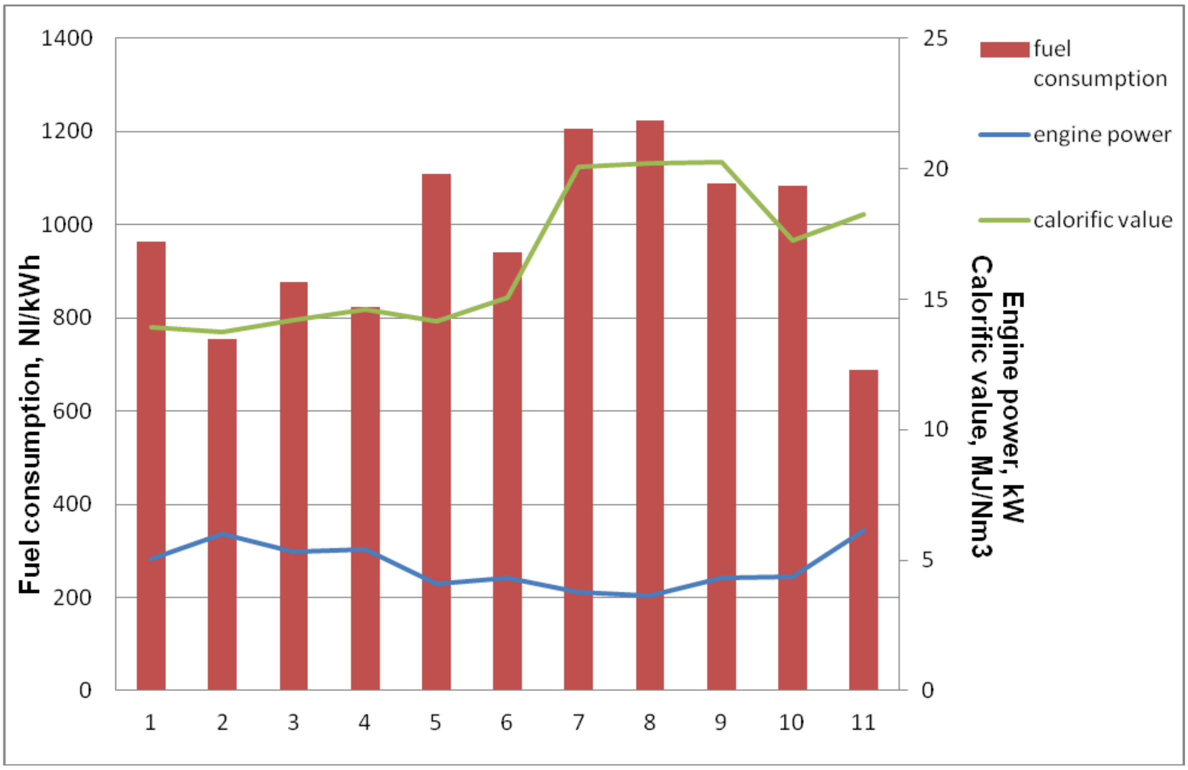

Figure 7. Engine power and fuel consumption with respect to the calorific value

In figure 8 concentration of particular compounds of exhausts for variable gaseous mixtures was presented. It appears that combustion gas mixture 1 (consisted of 1% of CO_2, 35% of CO, 10% of CH_4 and 53% of H_2) caused the highest emission of NO, CO and HC and also rather high emission of CO_2. Significant variability of exhausts composition for particular gas mixtures does not allow for the distinct assessment which mixture is the most advantageous in respect of ecological aspect. But it is possible to indicate a few the most optimal of them, such as mixture 7 (consisted of 6% of CO_2, 28% of CO, 38% of CH_4 and 28% of H_2) and 8 (consisted of 8% of CO_2, 39% of CO, 38% of CH_4 and 14% of H_2). It can be assumed that at higher content of methane, combustion of syngas fuel is the most optimal in terms of exhaust emission.

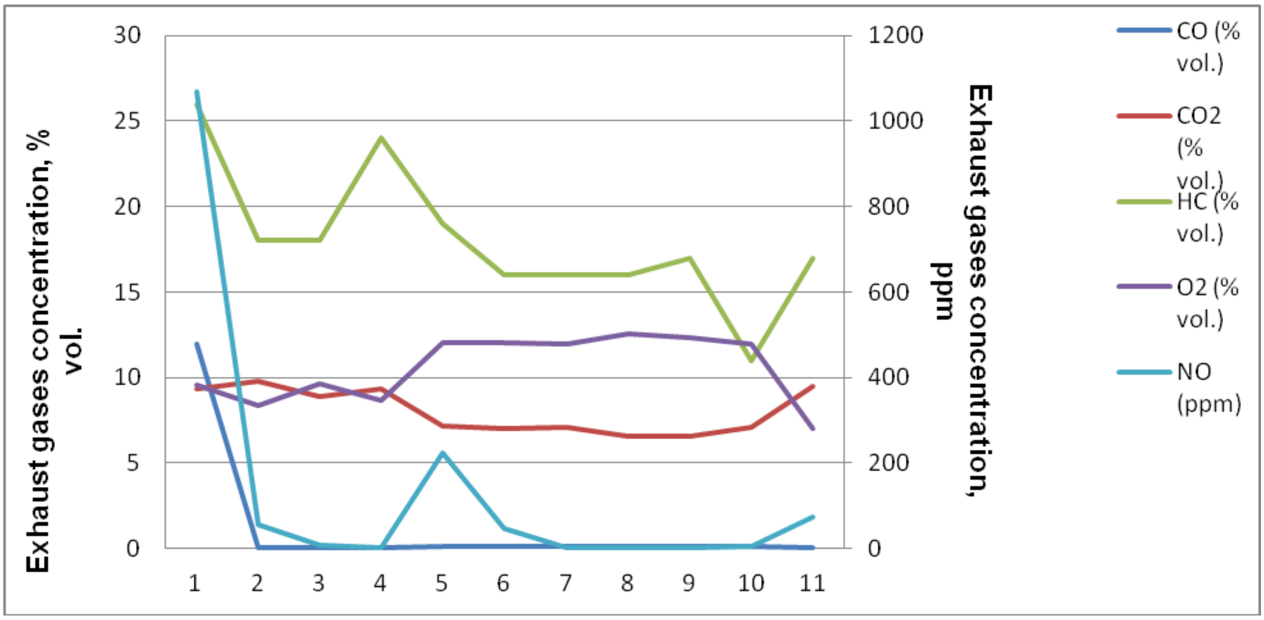

Figure 8. Exhaust gases concentration

5. Summary:

In presented researches evaluation of the efficiency of the internal combustion engine powered by SNG (*Substitute Natural Gas*) was provided. On a specially prepared test station research on eleven test gaseous fuels was carried out. The tests consisted of combustion mixtures of gases included in the syngas (H_2, CO, CO_2 and CH_4) with a variable compositions. As a result of the tests a lot of engine parameters were obtained, such as exhaust temperature, oxygen content in the exhausts, achieved engine power, hourly and specified fuel consumption, rotation speed, torque and concentration of exhaust compounds. The researches have shown relations between composition of combusted gas mixtures and engine parameters along with exhaust emission.

The most important conclusions of the tests are:

- calorific value has not impact on rotation speed of engine
- with the higher oxygen content in exhaust, rotation speed and engine power are lower (example in gas mixtures no. 5 to 10)
- except mixtures no. 1 and 5, the concentration of nitric oxide (NO) was very low; it is suggest to verify correctness of the fuel loaded system
- oxygen content influence on the exhaust temperature till 12% vol., below that value relation between amount of oxygen in and temperature was not observed
- it is hard to say which gas mixture is the most advantageous in terms of exhaust emission, but it is possibility to specify the optimal mixtures
- it is suggested to carry out the further tests with the gas mixtures to specified the best range of particular gases composition.

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