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TURBINE MODIFICATION OF NUOVO PIGNONE GAS TURBINE

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This paper deals with the environmental aspects of combustor modification on Nuovo Pignone gas turbines. The mentioned company is engaged in the transport of natural gas to the Slovak Republic and further to other European markets. Legislation considering emissions is getting stricter every year. Original Nuovo Pignone gas turbines would not be able to meet the required emission limits for NO_x and CO_r determined by legislation. Therefore, the company decided to modify seven gas turbines. Due to this reason, the combustion sections had to be replaced with a dry low emission system. These modifications were aimed at improvement of impacts of temperature on the emissions of NO_x, since the NO_x emissions are defined as thermal (there is an increase in emissions with the increase in temperature). Emissions were monitored continuously by an emission monitoring system (these data are continuously sent to the Office of Environment) and manually by a HORIBA PG-250 analyser. Gas delivery point is located in the flue pipeline, and data was processed by means of PC after reaching this point. The results lead us to conclusion that modification was an efficient and good solution in terms of economy, because this solution reduced emissions (from 300 $mg{\cdot}m^{-3}$ to 50 $mg{\cdot}m^{-3}$) and contributed to meeting of the stricter emission limits (from 370 $mg{\cdot}m^{-3}$ to 100 $mg{\cdot}m^{-3}$). Monitoring of the impacts of growing performance of equipment on emissions represents a possibility for further development of science in this field.

Keywords: analyser; diagnostics; emission; limit; measurement

In recent years, there have been more and more significant changes in the introduction of new technologies, which contribute significantly to the reduction of emissions distributed into the atmosphere by technological equipment (Peťková, 2010; Vitázek et al., 2014). The requirements for limits are constantly being updated and are always becoming stricter. The issue of the possibilities of emission reduction via technology equipment is highly topical (Solin, 2015; Zelenický, 1995; Šístková, 2016). This paper is focused on the possibilities of emission reduction from technological equipment used for transport of natural gas via gas combustors with Dry Low Emissions (DLE) system modification – the original combustion sections were replaced with DLE sections (Žarnovský et al., 2009).

The main aim of the gas turbine Nuovo Pignone T 23 MW modification is the replacement of the current combustion system with a highly efficient combustion system using the DLE system due to stricter emission limits for these sources of pollution of NO_x and CO_r.

Material and methods

This part of the paper describes the equipment and methods used for the DLE modification of original combustors.

The DLE combustion principle itself is based on the pre-mixing of air with the fuel before burning with the aim to achieve a reaction temperature lower than the temperature at which the great amount of NO_x emissions is produced. The DLE system is composed of several combustion devices which are installed on the gas generator. Each combustion chamber accurately controls the combustion temperature of the mixture of air and fuel. The dependence of emissions on the increasing temperature was determined the main benchmark (Kiss, 2002; Soares, 2008; Forsthoffer, 2011).

Characteristics of the original equipment of Nuovo Pignone T 23 MW gas turbine

Nuovo Pignone is a turbo machine with a nominal mechanical power of 23 MW.

The main parts of the equipment are:

1. Gas generator LM 2500 SAC – is a gas turbine with open cycle. It is used for the production of hot gases that drive a power turbine. There are 30 fuel nozzles along the circumference of the combustion chamber; they form a swirl flow and provide flame stability (Solin, 2015; Amaral, 2006).
2. Power turbine PGT 25 (Fig. 1) – is a two-steps turbine. It is used for the production of torque energy of the hot gases supplied by the gas generator. The gas generator with the power turbine contains a gas turbine PGT 25 (Žarnovský et al., 2009).
3. Gas compressor 602 PCL – this is a two-steps compressor with tangential input and gas output. The compressor is a single-casing machine, barrel type with a vertical parting plane. The gas compressor is driven by a power turbine via a claw clutch (Boyce, 2012; Peťková, 2010).

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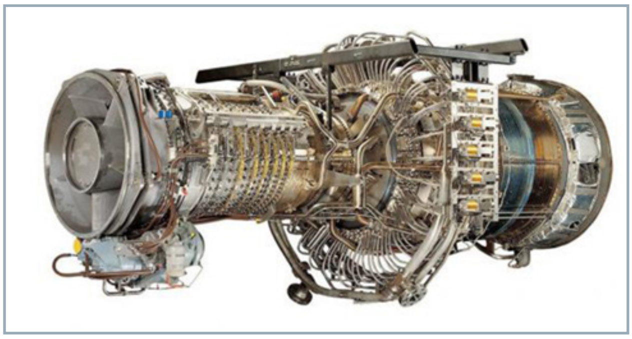

Fig. 1 Gas turbine PGT 25 DLE
Source: Peťková, 2010

Emission limits for Nuovo Pignone gas turbine

Until recently (until 31 December 2015), the valid emission limits for the Nuovo Pignone T 23 MW gas turbine were 370 mg·m^{-3} for NO_x and 100 mg·m^{-3} for CO. New legislation adopted the stricter emission limits that came into force since the 1 January 2016 and it was necessary to deal with this change. Finally, it was concluded that the best solution is to replace the original combustion section of turbo equipment with the DLE system sections (Kopný, 2004; Zelenický, 1995).

Monitoring equipment HORIBA PG-250

The portable equipment HORIBA PG-250 was used for monitoring; it also includes a system for sample treatment, which is used in the measurement of stationary systems. The analyser PG-250 (Fig. 2) performs the following operations: backing up the data for continuous measurement (Emission Monitoring System – EMS); the measurement of combustion efficiency; and adjusting of combustion processes. The analyser contains the complete equipment necessary for sample treatment: gas pump; electric cooler for gas; gas converter NO_2-NO; O_3 source for chemiluminescent reaction and preparation of reference gas (Solin, 2015; Eustream, 2005).

Monitoring process

While monitoring the concentrations of NO_x and CO for the Nuovo Pignone T 23 MW gas turbine equipment, the delivery point was located in the fuel pipe between the engine room and chimney. A nipple with a hole has been prepared here in order to insert the sample probe. Sampling was carried out by means of a sample probe with a length of 1.500 mm. The measurements were performed at a power range from 15 MW to the maximal power allowed by the device operating mode. In this point, it was necessary to maintain the identical duration of each measuring point without changes in the speed mode; this process took 30 minutes. Then, the sample was transported to portable system and it was subsequently cooled and dehydrated. The dry sample was moved to the analyser, where the emission values were measured. Afterwards, the data was transferred to the computer and the software converted these values to the final weight value by means of volume.

Fig. 2 Gas analyser HORIBA PG–250
Source: Solin, 2015

Results and discussion

The experiments, which were carried out during the verification of guaranteed machine parameters directly at the compressor station, were used for the result processing. The measurement was carried out by means of the emission monitoring system HORIBA PG-250.

Characteristics of the modified Nuovo Pignone T 23 MW gas turbine equipment

The modified combustion chamber of an annular type works on the lean-premix principle (with an excess of air). Combustion temperature is evenly distributed and maintained at a low level; therefore, the concentration of NO_x emissions is low even at maximal power. The modification affects the following machine parts of the Nuovo Pignone T 23 MW gas turbine:

- replacement of the DLE gas generator,
- replacement of the power turbine,
- modification of synthetic oil,
- modification of mineral oil,
- adjustment of the hydraulic system of the ignition device,
- adjustment of the ventilation system,
- modification of the scrubber,
- modification of the acoustic enclosure,
- modification of CO_2.

Measured values before modification

Table 1 shows the recorded operating parameters that were measured during the experiment.

Table 1 Operating parameters and measured emissions before modification

$t_{Exhaust\ gas}$ (°C)	$NO_{x\ Limit}$ (mg·m^{-3})	CO_{Limit} (mg·m^{-3})	NO_{xr} (mg·m^{-3})	CO_r (mg·m^{-3})
722	370.00	100.00	284.72	23.68
752	370.00	100.00	308.97	19.80
767	370.00	100.00	325.99	17.22
812	370.00	100.00	372.10	14.16

The graph (Fig. 3) showing the course of emissions at the specified operating parameters and the dependence of emissions in flue gases on temperature is based on the data provided in Table 1.

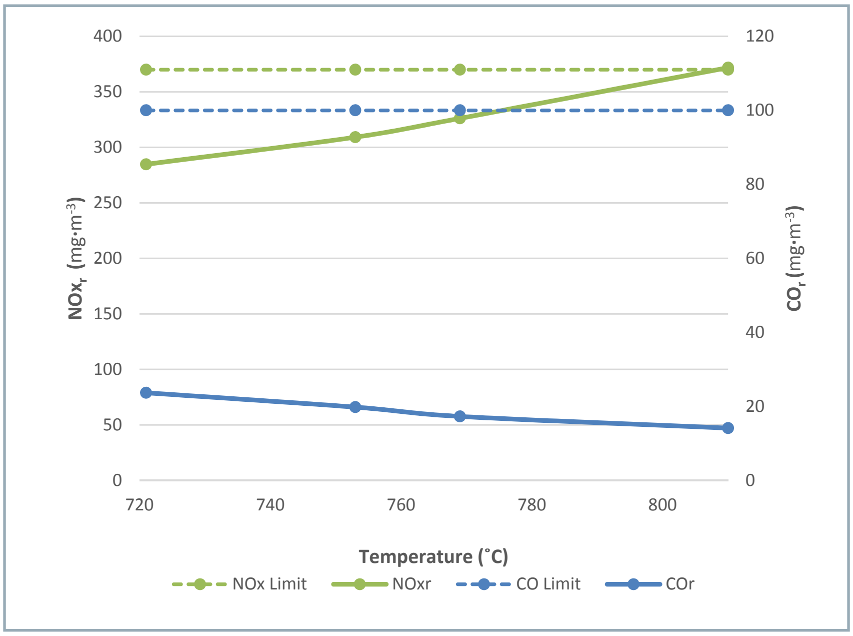

Fig. 3 The course of emissions depending on the flue gas temperature (before modification)

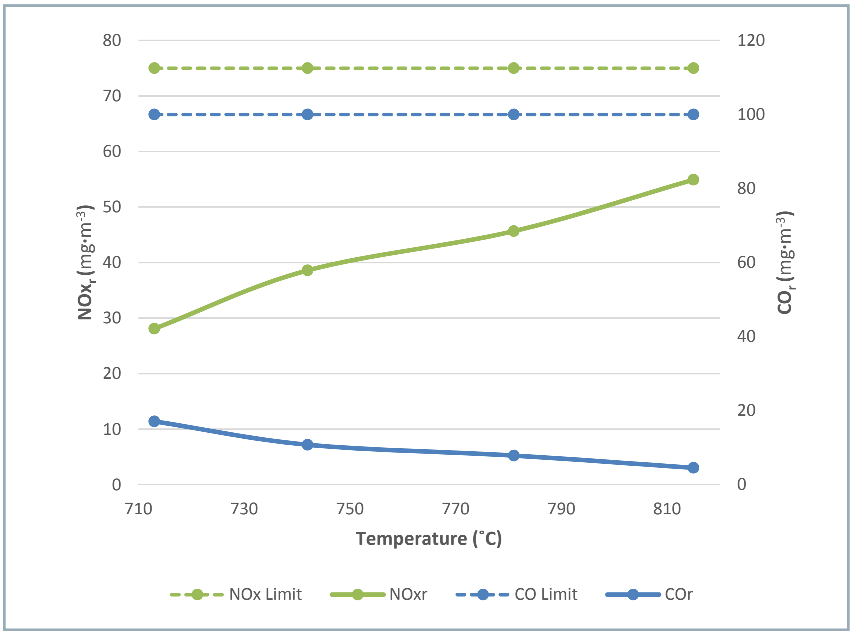

Fig. 4 The course of emissions depending on the temperature of flue gas (after modification)

Table 2 Operating parameters and measured emissions after modification

$t_{Exhaust\ gas}$ (°C)	$NO_{x\ Limit}$ (mg·m^{-3})	CO_{Limit} (mg·m^{-3})	NO_{xr} (mg·m^{-3})	CO_r (mg·m^{-3})
715	370.00	100.00	28.13	17.20
740	370.00	100.00	38.69	10.82
784	370.00	100.00	45.63	7.76
817	370.00	100.00	54.95	4.58

The values of NO_x emissions exceeded the emission limits determined by the current legislation since the maximal value reached 372.10 mg·m^{-3}.

Measured values after modification

Table 2 shows the recorded operating parameters measured after the gas turbine modification.

The graph (Fig 4) showing the dependency of emission values in flue gases on temperature is based on the data provided in Table 2. According to this graph, it can be stated that the maximal value of CO_r concentration reached 17.20 mg·m^{-3}; for comparison, the emission limit specified by the legislation is equal to the value of 100 mg·m^{-3}. It is necessary to emphasise that the values of NO_x concentration were significantly lower and reached a value of 54.95 mg·m^{-3} at maximal temperature, which is in conformity with the emission limits (75 mg·m^{-3}) valid since 1 January 2016.

Furthermore, the comparison of the data obtained from emission measurements for the period of machine operation before and after modification has been processed. A graphical representation (Fig. 5), comparing the individual values, has been provided for better view on the issue.

The values downloaded from the emission monitoring system were used as input values. This system is used for continuous monitoring of equipment during operation, during which the information is collected and subsequently evaluated in the database of the equipment measurement system.

At first, it is necessary to clarify that the results of this study clearly demonstrate the direct dependence of NO_x emission type production on increasing flue gas temperature. This argument can be supported with the findings published by Solin (2015), who also observed the dependence of NO_x emission production on the flue gas temperature in other types of combustion plants. NO_x emissions are frequently referred to as thermal NO_x as it is generally believed that they are produced at high temperatures; this phenomenon was successfully confirmed during the continuous monitoring by means of both the emission monitoring system and monitoring device HORIBA. Our

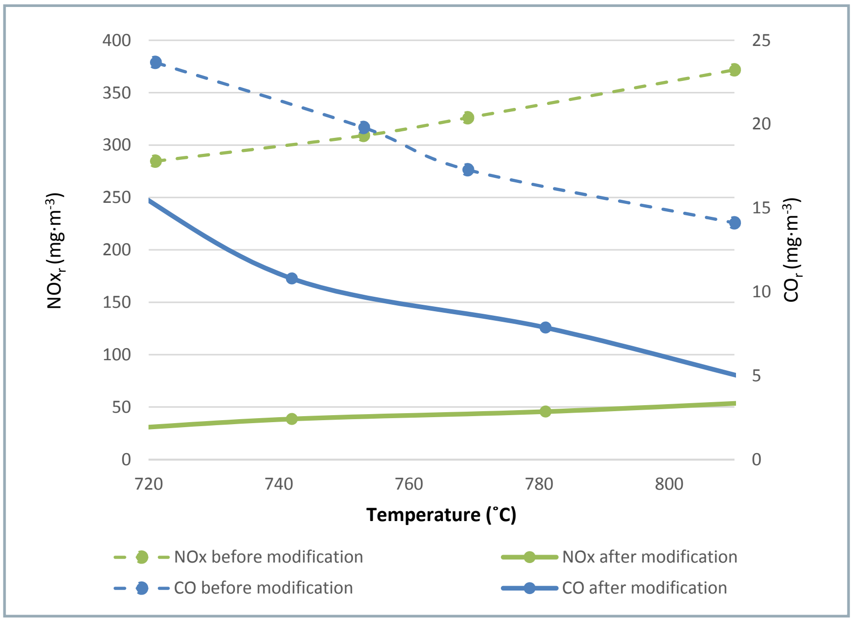

Fig. 5 The course of emissions before and after modification

experiment proved the claim that increasing temperature has a positive effect on the CO_r emission production since this emission type is a product of incomplete combustion at low temperatures. This statement is demonstrated in the work by Šesták (2007), who also observed the emission parameters of gas plants. Comparing the results, we can conclude conformity; however, this study also shows that lower CO_r emission production was achieved in the modified technology system at the same temperature than in the original combustion technology. This paper clearly shows the relation between the reduction of the NO_x emission production and the modification of combustion chamber system with DLE. Baláž (2011) also addresses the modification in this manner, because his research also shows a significant reduction of NO_x emission production after modification. Methods for CO_r control were observed by Mališ (2007); however, he dealt with them only theoretically.

All in all, it can be stated that the implementation of modifications in the turbo Nuovo Pignone gas turbine was a legitimate solution to the problem of high NO_x emission production; this step was suggested in order to reduce the additional CO_r emission production (since the plant was able to meet the limits of this emission type even before modification instalment), and thus to reduce the impacts of these devices on the environment.

Conclusion

By means of experiments, this paper demonstrates the importance of modification of the chosen turbo equipment in order to obtain safe operation and reduction of impacts on the environment due to a significant reduction of emission values in flue gases. The modification was carried out by conversion of a standard gas turbine combustion SAC to the DLE system. The performance of original technology with standard combustion SAC is not always in line with the valid Slovak legislation in term of emission limits. The Nuovo Pignone T 23 MW gas turbine was installed because the plant would have not been able to meet the required emission levels (NO_x 75 mg·m^{-3}) determined by the new legislation. Comparing the measured values of emissions in flue gases before and after modification, it can be said that emission values (max. 55 mg CO_r m^{-3}) decreased by several times, and the equipment is fully capable of further operation after 1 January 2016, when stricter emission limits came into force. Modification of the combustion chamber led to the successful reduction of emissions. In respect to the global situation, it also contributed to the continuous reduction of emissions distributed to the atmosphere and thereby reduced the distortion of the environment of all organisms, including humans.

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