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Afterburning Installation of 2xST 18 Cogeneration Power Plant – Investigations on Combustion and NO_x Emissions

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The new generation of afterburning installations of the cogeneration groups with gas turbine will have to take into consideration the emissions, efficiency and process requirements. The paper presents the research performed at cogeneration power plant 2xST 18 - Suplacu de Barcau, Romania, on afterburning installation flow and NO_x emissions, the stage of CFD simulations and test bench experiments. For an integrated analysis of the afterburning installation, at different functional configurations of the cogeneration group, were studied: NO_x emission at heat recovery steam generator stack, burning gases temperature at the end of afterburning chamber, infrared image of the upper part of burner. Data analysis, obtained at partial loads allowed obtaining an experimental burner that has 30 % less NO_x emissions than the one in the power plant. Experiencing the burner at nominal load, currently mounted on test bench, will permit the validation of numerical model and verification of performances.

1. Introduction

In compliance with legislative requirements relating the NO_x emissions, new technologies and investigation methods are required in order to study the burning installations (Belohradsky and Kermes, 2012). Afterburning installations and combustion chambers of stationary gas turbines need to meet the challenges of an extremely low emissions and high efficiency at partial loads. Research on combustion control with special sensors, demonstrative industrial applications at burners and gas turbines, aimed to develop new technologies which maintain a high efficiency of gas turbine in afterburning installation (Samuelson and Miyasoto, 2002). The flame shape and temperature control of the entire process are critical parameters that influence the NO_x emissions reduction. A uniform flow distribution is an important factor which contributes to a good functioning of the afterburning process and assures the heat recovery steam generator performances. The large amount of resources, including time, required to develop new afterburning installations makes the CFD modelling environment a good candidate to analyze different geometries of the burner (Cammarata et al., 2008). The complexity of the resulted processes from the interaction of gas turbine-afterburning installation-heat recovery steam generator imposes an integrated analysis of the afterburning installation within the cogeneration group (Barbu et al., 2010). Starting from the existing afterburning installation of the 2xST 18 - Suplacu de Barcau cogeneration power plant, the paper presents the research performed to obtain a afterburning burner with 30 % less NO_x emissions. The research on the afterburning installation was performed in several stages, in the cogeneration power plant and on the test bench. The research followed mainly the flow inside the burner (materialized by infrared analysis at the upper part of the burner - t_{IR} and gas temperature at the end of the afterburning chamber - t_{pc}) and NO_x emissions (measured at the heat recovery steam generator stack).

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2. Experimental Part

2.1 Cogeneration power plant 2xST 18 – Suplacu de Barcau

The cogeneration power plant 2xST 18 - Suplacu de Barcau (Romania) is composed of two cogeneration groups, that can function in parallel or individual. Each group has the components presented in Figure 1 (left). The heat recovery steam generator is fire-tube type, composed of: afterburning chamber - not cooled, superheater, pressure body and the system of economizer-water preheater that assures the necessary parameters for supplying with water the pressure body (Barbu et al., 2012). The afterburning installation is composed mainly of: burner, gas combustible/air control system, the supplying system with gas combustible and the automation installation (interconnected with the power plants automation). The afterburning burners of the two cogeneration groups are positioned in mirror. Each burner is "FlueFire" type (inset – Figure 1 left) and assures at the end of the combustion chamber a nominal temperature of 770 °C. Within the group, the burner is placed directly in the burning gases from the gas turbine, having 21 burning modules (named ST 18), positioned on 3 ramps of combustible gas. The burning gases from the gas turbine (or the fresh air from the fan) are introduced through an adjustment section (that connects to the by-pass system) at the "FlueFire" burner. The tests made at the commissioning of the power plant, forced the introduction of a fixed concentrator upstream of the burner (on the trajectory of air/gas turbine burning gases, behind the burning modules). The burner CFD simulations (Barbu et al., 2008) showed that the flow distribution within the burner can be improved by introduction of a mobile concentrator (in "v" shape, the v being oriented in opposite direction of oxygen carrier flow).

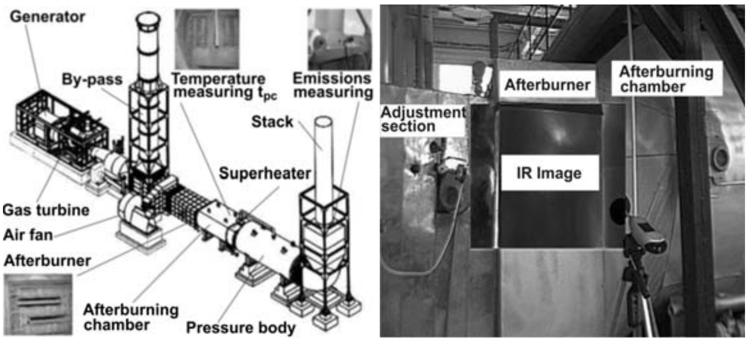

Figure 1: Equipment position in cogeneration group with measurement points (left) and infrared visualization area at the upper part of the burner (right)

The mobile concentrator can be placed in the desired position modifying the interaction between combustible gas jet and the burning gases from the gas turbine or air. Before the experiments the mobile concentrator was mounted just at group 1, the second one remaining with the fix concentrator. The cogeneration group configuration permits the functioning in three versions. Version I is the basic model, and through the by-pass ensemble (Figure 1 left) it can be easily switch between all the functioning versions. In the first version the afterburning installation functions on combustible gas with burning gases form the gas turbine. In the second version the afterburning is stopped and the heat recovery steam generator works only with burning gases from the gas turbine. When the gas turbine does not function the afterburning installation with heat recovery steam generator works on combustible gas with fresh air, which represents version III. In this version the ratio air/combustible gas is adjusted through a system of actuator – cam strip positioner and two interconnection bars. Adjustment of the air flow rate is made by stopping the fan suction of fresh air by means of jalousie system. This jalousie system is actuated by an arm which presents a recess on its length. The arm is operated by one of the interconnection bar connected to actuator - cam strip positioned system. Normally the bar is placed in the middle recess. The second interconnection bar operates the control lappet of the combustible flow. By this way a predetermined ratio of combustible gas/air is achieved.

2.2 Methodology and apparatus

Measurements were performed in the power plant to analyse the effect of the mobile concentrator on the flow inside the burner. In order not to disturb the technological process, the measurements were performed on the cogeneration groups at partial loads. The measurements at group 1 (with mobile concentrator – shifted at maximum position, in the direction of the flow gas) were performed just in version III and at group 2 (with fix concentrator) in configuration I and II. For the NO_x emission measurements a

MRU type - Analyzer Vario Plus Ind. was mounted at the base of the heat recovery steam generator stack (inset – Figure 1 left). This gas analyser allows the measurement of NO_x by converting NO in the range of 0...1,000 ppm (±5 ppm). The analyser was set for gas combustibles, at 3 % oxygen. By reporting at normal conditions (0 ^{0}C and 101.325 kPa) the NO_x emissions are obtained in mg/Nm^3, on a dry basis and at 3 % O_2. The temperature of the burning gases at the end of the afterburning chambers (t_{pc}) was measured with a thermocouple (with an error of ±5 ^{0}C, according to EN 60584 part 2), placed at a distance of 2,970 mm from fixing flange with the burner (before superheater, inset – Figure 1 left). The exterior superficial temperature was determined with the help of a Fluke infrared camera - type Ti45FT (error ±2 ^{0}C), by visualising the upper part of the burner (Figure 1 right). Air quality measurements were performed with a mobile laboratory, specially equipped. The process parameters of the gas turbine, heat recovery steam generator and afterburning installation were read on display or locally. Emissions data was correlated with exterior superficial temperature profile by report to the measurements hours. Gas combustible/air control system was analysed from the point of view of the bar position. This was done related to driving arm of the jalousie, by recording the emissions at the heat recovery steam generator stack, infrared visualisation of the upper part of the burner (similar to the study of flow inside the burner). The tests were performed at the same loads of the afterburning installation (58.8 %, 63.3 % and 65.7 %), for each three positions of the bar driving the arm (left, middle, right). The equipments used for measurements are the same as the equipments used at investigating the flow inside the afterburning installation burner. Based on the measurements in the power plant, the CFD simulations were repeated. Based on these new results it was concluded that by flaring the flame limiting at 15°, a reduction of the NO_x emissions is achieved, in the end obtaining a new burning module - named ST 18-15. The numerical simulation started from the exaction drawings of the burning module, transposed in 3D model. The flow domain for the simulations was selected taking into account the total number of burning modules and their position into the afterburning chamber. It resulted the domain for a single module but with boundary conditions (periodicity, inlet and outlet with mass flows and pressures). The simulations were made using k-ε turbulence model, no slip walls and PDF reaction table to model the combustion. The PDF model for combustion uses NASA thermodynamic equilibrium model and coefficients to establish the composition into the flow domain where combustion takes place depending on the cell parameters calculated by the flow solver. The grid was unstructured with about 2 millions cells, the finest mesh being in the vicinity of the burning module. Reference temperature at a distance of 2.5 m (towards the burning module) was established at 770 °C and the error in evaluation was under 1 %.To verify the data obtained by simulation and to study the NO_x emissions in laboratory conditions, an experimental monomodular burner was designed, with a different geometry from the one in the power plant (test bench adaptation – Figure 5). The tests were performed at partial loads on a test bench consisting of parallelepipedous enclosure (890x890x990 mm), with glass side walls, with an access door on one of the sides (Barbu et al., 2011). On the test bench was studied only the flow inside the burner and the NO_x emission, the ratio combustible gas/air being manually controlled. In the first step the monomodular burner was tested with the ST 18 module, on natural gas and air (0.4, 0.56 and 0.7 kg/h - natural gas flow rates). At the same functioning conditions (natural gas flow rates, burning air flow rates, etc.) the burner with ST 18-15 module was tested. Considering ST 18 as reference, it was aimed that at the exit of the parallelepipedous enclosure the oxygen concentration to be comparable with the one measured at the heat recovery steam generator stack. The same equipments as the ones used in the power plant were used during this measurements. Temperature distribution inside the flame has been made using thermocouples (PtRh30% - PtRh46% type) placed on the frame. The experimental results referring at NO_x emissions were processed with Microsoft applications. The data obtained by infrared visualizations were processed with the dedicated software of the Fluke - Ti45FT type camera. Based on the theoretical and experimental data, by combining the ST 18-15 module with the mobile concentrator used at group 1, a new model of burner module was obtained - type ST 18-R.

3. Results and discussions

Figure 2 (left) presents NO_x emissions variation at the heat recovery steam generator stack of group 1 (version III with mobile concentrator). Infrared images of the isotherms, obtained at the upper part of the afterburning installation (Figure 1 right) during power plant functioning are presented in Figure 3. In this case group 1 is in version III with mobile concentrator and group 2 is in version I with fix concentrator. The markers separate the isotherms with measured temperatures (t_{IR}) above 125 ^{0}C (light colour region). It can be observed that at group 1 (Figure 3 left) the area covered by the high temperature isotherms (t_{IR}>125 ^{0}C) is much bigger that the case of group 2 (Figure 3 right). Even if a complete visualisation of the burner was not possible, isotherms configurations indicates an increase of the comburent – natural gas carrier jet interaction, and by default a better flow in the upper part of the burner, at group 1. The results of the tests performed on the combustible gas/air control system in terms of NO_x emissions at the heat recovery steam generator stack, are presented in Figure 2 right for all three positions of the bar. The burning gases temperature variation at the end of the afterburning chamber, at different partial loads (maximum load – 65.7 %, minimum load 58.8 %), shows different temperatures as: 72 °C (left), 67 °C (middle), 59 °C (right), depending on the bar position (table 1). So, the adjustment range of the gas temperature is reduced as the driving bar is shifted from left to right, while the corresponding maximum temperatures are rising. This temperature increase is confirmed by infrared analysis, the area covered by the high temperature isotherms growing as the load is increased from 58.8 % to 65.7 %. For a trade-off between the adjustment range and the maximum value of the burning gases at the end of the afterburning chamber, the interconnection bar was placed in middle of recess. For the two described situations, the NO_x variation (Figure 2) can be characterised by an exponential curve, with a relatively slow increase in the analysed range of temperature (500 - 700 °C). By comparing the two data sets, power plant and numerical simulation, it resulted that the numerical simulation gives satisfactory results (in a limit of ± 10 %) only for temperature variation and oxygen content measured at the heat recovery steam generator stack (Barbu et al., 2008). Numerical simulations showed that a flare bigger than 15^0, at the ST 18-15 burning module, negatively influences the NO_x emissions. It is possible that this performance decrease to indicate a detachment of the boundary layer. This phenomenon is insufficiently studied in present, supplementary theoretical and experimental investigations being necessary. Laboratory comparative experiments (Figure 4, 5) showed that flame of ST 18-15 module better fills the furnace and NO_x emissions decrease with about 30 %, at a natural gas flow rate of 0.7 kg/h. At this flow rate, the temperature along the height of the enclosure is smaller around the ST 18-15 burning module (Figure 4 right) in compare to ST 18 module. In the same time the temperature markers in Figure 5 show that the temperature distribution is homogeneous at ST 18-15 module.

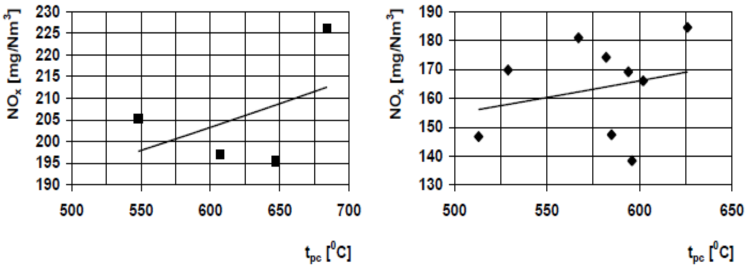

Figure 2: NO_x emissions variation at the heat recovery steam generator stack function of gas temperature at the end of the afterburning chamber for group 1 (left) and cumulated for all three positions of the driving bar (right) - version III with mobile concentrator

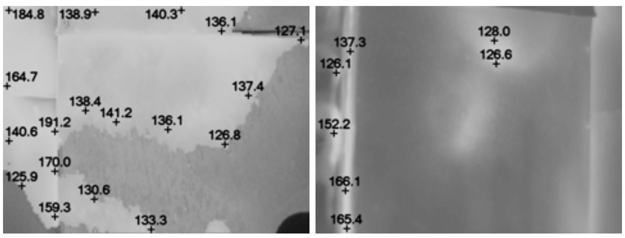

Figure 3: Isotherms configurations in infrared analysis of afterburning installation tests at groups 1 and 2: t_{pc}=552 ^{0}C (left - group 1, version III with mobile concentrator); t_{pc}=536 °C (right - group 2, version I with fix concentrator)

Table 1: Burning gas temperature, at the end of afterburning chamber (t_{pc}), at different partial loads and positions of the driving bar

			Load [%]	
	Position of bar	58.8	63.3	65.7
t_{pc} [^{0}C]	Left	513	582	585
	Middle	529	594	596
	Right	567	602	626

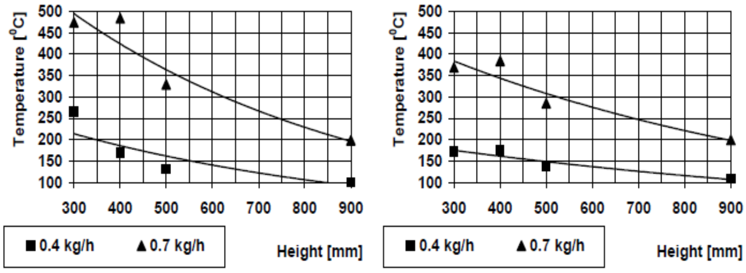

Figure 4: Temperature variation along the enclose height, at test bench experiments of the monomodular burner – with ST 18 module (left) and ST 18-15 module (right)

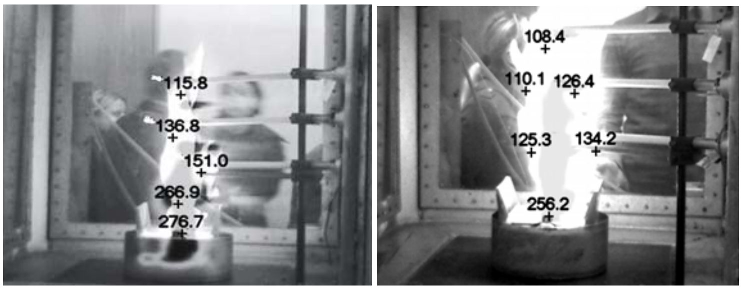

Figure 5: Isotherms configurations in infrared analysis during tests on the test bench of the monomodular burner – with ST 18 module (left) and module ST 18-15 (right), on natural gas with air (at a flow rate of 0.7 kg/h of natural gas)

NO_x variations during test bench experiments of the ST 18 and ST 18-15 burning modules (for natural gas flow rates in range of 0.4 - 0.7 kg/h) can be expressed by Equations (1) and (2). Even if burning module experimented on the test bench was the same type (ST 18) the different geometries of the burners (burning chambers), different thermal loads, etc. influenced the NO_x emissions. So, Equation (1) does not characterize the NO_x emissions from the burner which was tested in the power plant.

$$NO_{xST18} = 0.258\exp[0.0065(273.15+t_{pc})] \quad (1)$$

$$NO_{xST18\text{-}15} = 0.102\exp[0.0073(273.15+t_{pc})] \quad (2)$$

The theoretical and experimental investigations allowed obtaining the ST 18-R burning module (ST 18-15 burning module with mobile concentrator). At nominal functioning temperature of the afterburning installation (770 ^{0}C) the numerical simulations show for the ST 18-R a reduction by three times for the NO_x emission in compare to the old ST 18.

4. Conclusions

The experiments performed at the cogeneration power plant 2xST 18 on the afterburning installation (with ST 18 modules) showed that the flow inside the burner is improved by introducing the mobile concentrator. Laboratory tests on a monomodular burner proved that ST 18-15 module (obtained by numerical simulation) presents a reduction of the NO_x emissions of more than 30 % (at a flow rate of 0.7 kg/h natural gas). The CFD simulation and tests conducted to develop an experimental multimodular burner (with burning modules ST 18-R) at which the NO_x emissions (estimated through simulation) are three times less in compare with the one from the power plant. At present, the burner with ST 18-R module (3 modules) with similar geometry with the one from the cogeneration power plant placed on the test bench for following experiments. Test bench experiments of such burners will permit obtaining the emissions at nominal load and improve the numerical model of NO_x emissions. At the same time are expected an increase of the noise level and a drop of pressure at burner, in compare with the burner from the power plant, further optimization study being necessary.

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