Integrated analysis of afterburning in a gas turbine cogenerative power plant on gaseous fuel

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Abstract: - The afterburning installation allows the increase in the cogenerative group's flexibility according to the requirements of the technologic process and increases the steam quantity delivered by the heat recovery steam generator. The requirements concerning the development of high performance equipments with low environment impact and high flexibility have increased lately. Therefore a complex analysis is needed for obtaining the necessary data for designing the afterburning installation. The paper presents the researches carried out at Suplacu de Barcau gas turbine cogenerative power plant on the afterburning installation as well as the phase of bench experimentations for an intimate research of the processes and for the elimination of disturbing factors in the plant. The researches at the cogenerative plant were carried out in different operating conditions, in terms of stack emissions, noise, external superficial temperature profile and electric energy quality.

Key-Words: - Afterburning, Gas turbine, Cogeneration, Noise, Infrared, Emissions, Flue gases

1 Introduction

Through a more efficient utilization of the fuel the cogeneration leads on the one hand to decrease in costs and increase in product competitiveness and on the other hand to a significant decrease of emissions. The development of gas turbines in terms of performances as well as life time, exploitation cost and reliability made these installations preferable for cogenerative processes, the reduced investment costs leading to 3 – 4 years dumping and 15 – 20 years total life cycle. The improvement of the overall efficiency of a cogenerative power plant depends on the use of waste heat from the turbo-engine and is accomplished by using a heat recovery steam generator. The performances of the heat recovery steam generator depend on the turbo-engine operating conditions making the steam parameters difficult to control. It is possible to apply supplementary fuel combustion (afterburning) for increasing the steam flow, compared to a heat recovery steam generator as the combustion turbine process consumes a small fraction of oxygen. The afterburning is commonly used in aviation to increase the thrust of supersonic aircraft engines, its introduction in cogenerative applications leading to increased overall efficiency of the cogenerative group. The trend in the field of heat recovery steam generator and afterburning installations are related to the development in gas turbines. The increase in the temperature of the turbo-engine exhaust temperature requires new materials that withstand operating regimes in terms of appropriate norms pollutants. Turbo-engine performance is affected by ambient temperature and load, which affect the heat recovery steam generator operation. The burned gases flow is turbulent and unevenly distributed in the outlet cross section of the turbo-engine. In some areas at the heat recovery steam generator inlet backflow may occur. A uniform distribution of flow is an important factor participating to afterburning good functioning and ensuring the heat recovery steam generator performance. The gases discharged from the turbo-engine already have a high temperature (about 550 °C) leading to high burner thermal efficiency [1]. Network type burners are designed to evenly distribute the heat in the heat recovery steam generator cross section which requires a careful oxygen supply in order to avoid high emissions of pollutants and flame length variation. Designing the turbine-afterburning-heat recovery steam generator system must take into account these variables to ensure the steam parameters required by the technological process. The major manufacturers of afterburning equipment aim the accomplishment of high performance installations with low exhaust emissions. As a result of these trends researches have been carried out at 2xST 18 – Suplacu de Barcau Cogenerative Plant (superheated steam boiler) concerning the afterburning installation under contracts 22-108/2008 and 21-056/2007 (Partnerships in priority areas), financed by Ministry of Education, Research and Youth [1,3]. The researches aimed to analyze the processes in the afterburning installation at 2xST 18 Cogenerative Plant at different operational regimes in order to improve the performance. The research examined the afterburning as part of the cogenerative group in terms of stack emissions, noise, surface temperature profile and power quality. Based on these measurements and a numerical model [1] the combustion modules have been redesigned and experiments have been started to establish the performance of the new burner geometry.

2 Afterburning at 2xST 18 - Suplacu de Barcau Cogenerative Plant. Integrated analysis system for afterburning

2xST 18 – Suplacu de Barcau Cogenerative Plant (Fig. 1), beneficiary PETROM Group OMV, is located in Romania, Bihor county, 75 km from Oradea. 2xST 18 – Suplacu de Barcau Cogenerative Plant simultaneously produces electricity and heat and is the first product of its kind equipped with gas turbines, designed and built entirely in Romania by Romanian specialists. The Plant was fully put into operation in 2004, operating within the oil scaffolding of Suplacu de Barcau.

Fig. 1 View of 2xST 18 Suplacu de Barcau Cogenerative Plant

2xST 18 Suplacu de Barcau Cogenerative Plant consists of two groups (Fig. 2) that can operate simultaneously or separately. Each group is composed mainly of one ST 18 gas turbine, one heat recovery steam generator, one afterburning installation and associated installations. The heat recovery steam generator corresponding to each cogenerative group is ignitubular type, with two gas lines – one horizontal, the other vertical, consisting of: afterburning chamber without water cooling; superheater to ensure steam at 300 °C; pressure body to provide saturated steam; saver assembly – water preheater to ensure water parameters needed for pressure body feeding [2]. The exhaust gases produced by the turbo-engine pass through the burner of the afterburning installation where they reach the corresponding temperature. The gases follow the horizontal line of the heat recovery steam generator (superheater – pressure body) and then the vertical one (saver – water preheater – stack). 2xST 18 Suplacu de Barcau Cogenerative Plant works in automatic mode, the operating personnel receiving information at the control panel by optical signal boxes or acoustic signals on the occurrence of irregularities on supervised parameters or on production of damage. Certain parameters (pressures, temperatures, flow etc.) of the equipments from the Plant may be stored or displayed through a data acquisition system. The electricity is used in the scaffolding to drive the reduction gears of the wells, compressors, pumps as well as for the lightning, and the thermal energy (steam) is injected into the deposit, as required by the technologic process of oil extraction and /or other requirements of the scaffolding (buildings or technological pipelines heating).

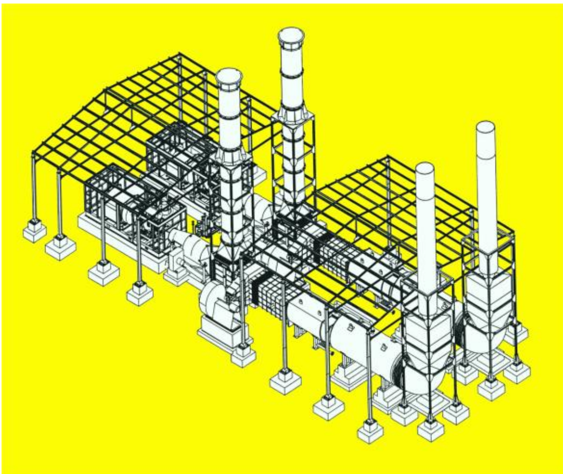

Fig. 2 Machines layout at 2xST 18 Suplacu de Barcau Cogenerative Plant

2.1 The afterburning of 2xST 18 - Suplacu de Barcau Cogenerative Plant

The afterburning installation (burner with automation) of 2xST 18 – Suplacu de Barcau Plant was delivered by Saacke Company (www.saacke.com - Germany) with the characteristics calculation in Table 1 [2, 3]. The burner (Fig. 3) delivered by Saacke (produced by Eclipse - Netherlands) is "FlueFire" type, dedicated to this type of application. It can be placed directly into the combustion gases between the turbo-engine and heat recovery steam generator, but can also function on fresh air. The burner has 21 firing modules placed on three natural gas supply ramps and two modules for flame propagation. In the "FlueFire" burner the gases from the turbo-engine are introduced through an adaptation section, ensuring an intimate mixture with the fuel through vortex generation of the gases in the combustion fuel jets. This leads to cooling and stabilizing the front burner combustion, allowing high temperatures downstream, at a low content of pollutants. The combustion air supplied by a fan (Fig. 4) is introduced in the adaptation section through a distribution system designed to ensure a uniform distribution in the cross-section as the emissions depend on flow uniformity in the cross-section, speed, oxygen concentration etc.

Table 1 Technical data for the afterburning installation of 2xST 18 - Suplacu de Barcau Plant

No.	Parameter		Value
1	Natural gas pressure	before throttle	0,5-2 bar
		after throttle	0,4 bar
2	Thermal power	with turbo-engine gases	2,4 MW
		with air at 20 ^{0}C	6 MW
3	Maximum volume flow rate of turbo-engine gases		8,75 kg/s
4	Gases temperature at the afterburning burner inlet		524 ^{0}C
5	Gases temperature at the afterburning chamber outlet		770 ^{0}C

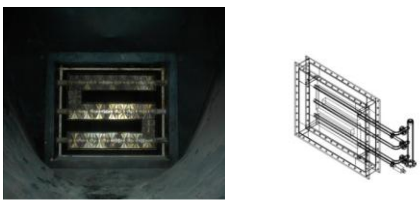

Fig. 3 The burner of the afterburning installation at 2xST 18 Cogenerative Plant

Fig. 4 The fan and the air inlet area in the adaptation section

The burner modules are constructed of refractory steel and laser cut to ensure the necessary uniformity. Each module is fixed to the collector-distribution pipes using two nozzles of fuel gas so they are allowed free expansion of the assembly. The burner is lit by a pilot burner located at the bottom of the afterburning burner, the flame monitoring being provided by a "DURAG D-LX 100 UL" UV detector located in the upper area.

2.2 The afterburning integrated analysis system

The CFD numerical analysis [1] of the burner in the afterburning installation of 2xST 18 – Suplacu de Barcau Plant showed that the air distribution in the burner can be improved. In this context a concentrator that modified the air distribution in the flame was installed in group 1. The situation in group 2 remained unchanged from the moment of commissioning the plant. To see the influence of the concentrator on the combustion process an analysis in terms of stack emissions, noise, surface temperature profile and the quality electricity was used for different regimes of the groups. The measurements in industrial conditions were made in several stages on the two groups of plant, before applying the global optimization solutions, to avoid the technological process disruptions. These measurements were performed only at partial load. For locally measuring the noise from the afterburning installation a Metravib SOLO 01 dB sound meter was used, mounted at one meter distance from the afterburning installation burner. The map to determine the global noise level was prepared based on the measurements made with two measurement chains using B&K 2250, respectively 01dBMetravib SOLO sound meters. Air quality measurements were made by specially equipped mobile laboratory. For measuring the emissions a Horiba PG 250 analyzer was used with the probe installed at the heat recovery steam generator stack (Fig. 5) in 2xST 18 – Suplacu de Barcau Plant. The exterior surface temperature profile was measured using a Fluke infrared camera, type Ti45FT, targeting being done at the top of the burner of the afterburning installation (Fig. 6). The process parameters for the turbo-engine, heat recovery steam generator and afterburning were read either on display (Fig. 7) or locally. Data correlation was made in terms of pollutants, noise, exterior surface temperature profile and power quality by reporting the recording time. Electro-energetic measurements were made in the electric generator cell (Fig. 8) by means of measuring transformers. The electro-energetic measurements were made using both fixed devices mounted in panels (ammeters, voltmeters, active and reactive energy meters) and portable equipment (power network analyzer and power quality type CA 8332B).

Fig. 5 Mobile laboratory and Horiba PG 250 analyzer with the probe installed at the heat recovery steam generator stack

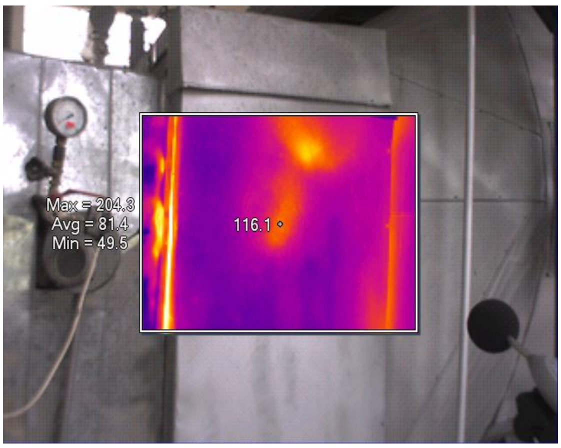

Fig. 6 Scope of endorsement by the Ti45FT type Fluke camera and sound level meter

Fig. 7 Command and control room at 2xST 18 Plant with data acquisition system

Fig. 8 Power distribution station (left) and CA 8332B network analyzer (right)

3. Experimental data and numerical modelling

The data obtained so far consist of experiments at 2xST 18 Cogenerative Plant, numerical simulations in CFD environment and bench experiments on gas and air.

3.1 Data obtained at experimentations in 2xST 18 Cogenerative Plant

In a first stage the noise map for the second group of the power plant (without air concentrator) have been performed), to have comparative data for recording state of local noise at the afterburning system burner. The noise map was first realized by adding the sound power of 12 measured points close to the turbo-engines, and then correction of sound directivity and correction for wall reflections have been achieved. Also based on measurements with sound level meter in 50 points outside and inside around the cogeneration plant, the noise map presented in Fig. 9 has been verified and corrected by changing the acoustic parameters of the software related to reflections and transmissibility trough walls. Note that in the area of the afterburning installation, burner noise level is in the 80 - 85 dB range, and the strong noise curves deformation and large values are met in the turbo-engines hall area.

In the second stage were performed measurements on group 1 (with air concentrator) in terms of NO_x emissions, noise and superficial external temperature profile to the heat recovery steam generator operation of the afterburning working on fresh air. During this time group 2 worked in cogeneration regime (turbo-engine + afterburning + heat recovery steam generator). There was obtained the set of experimental data corresponding to five operating regimes, defined by the temperature of the flue gases at the end of the afterburning chamber (t_{ca}): 500 ^{0}C, 552 ^{0}C, 604 ^{0}C, 645 ^{0}C, 700 ^{0}C. Variation of NO_x emissions and noise, locally recorded in the afterburning installation burner, depending on the temperature of the flue gases, recorded with a thermocouple at the end of afterburning chamber, is given in Fig. 10.

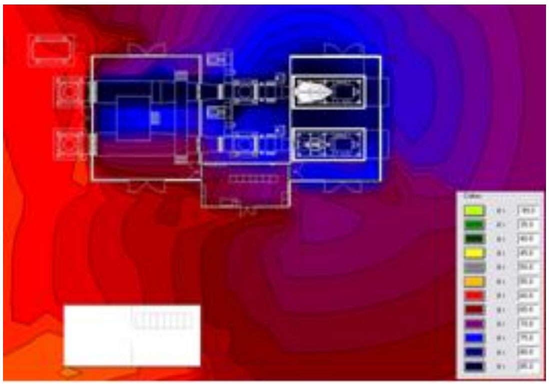

Fig. 9 Noise Map of 2xST 18 Cogeneration Power Plant - Suplacu de Barcau, group 2 in operation and group 1 stopped

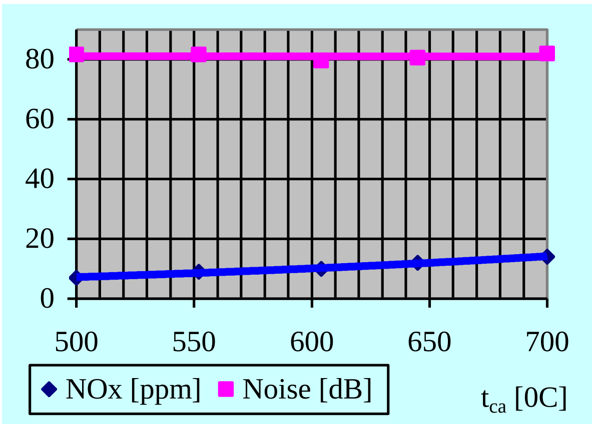

Fig. 10 NO_x and noise variation depending on gas temperature at the end of afterburning chamber - group 1 (afterburning + heat recovery steam generator)

From Fig. 10 we can see that the increase of flue gas temperature leads to NO_x emissions increase, while the noise is almost constant, at approx. 81 dB. In terms of the superficial external temperature profile, concerned according to Fig. 6, there is a growing of region occupied by isothermal line with temperatures above 200 ^{0}C (Fig. 11, left), as the temperature at the end of afterburning chamber grow from 500 ^{0}C to 645 ^{0}C. In the third stage we've performed noise, emissions and superficial external temperature profile measurements at the group 2 (without air concentrator). The cogenerative group was functioning without afterburner (turbo-engine + heat recovery steam generator) and with afterburner (turbo-engine + afterburning + heat recovery steam generator). There were obtained two experimental sets of data. One of the experimental data set corresponds to three different working regimes of the turbo-engine + heat recovery steam generator configuration, and is defined by the flue gases temperature measured at the end of the afterburning chamber (t_{ca}), respectively: 423 ^{0}C, 437 ^{0}C, 475 ^{0}C. The other experimental data set corresponds to turbo-engine + afterburner + heat recovery steam generator configuration and has been conducted at followings flue gases temperatures measured at the end of the afterburning chamber (t_{ca}): 536 ^{0}C, 569 ^{0}C, 605 ^{0}C, 645 ^{0}C. In Fig. 11 and 12 (right side) are given the isotherms configuration and the histogram for turbo-engine + afterburning + heat recovery steam generator arrangement. Working at fresh air rating, more than 645 ^{0}C, the region occupied by the isotherms is reduced, but is much larger than the isotherms corresponding to the group 2 (without air concentrator – Fig. 11 right side) working in cogenerative regime (turbo-engine + afterburning + heat recovery steam generator) or turbo-engine + heat recovery steam generator (without afterburner). These observations are confirmed by the histograms in Fig. 12.

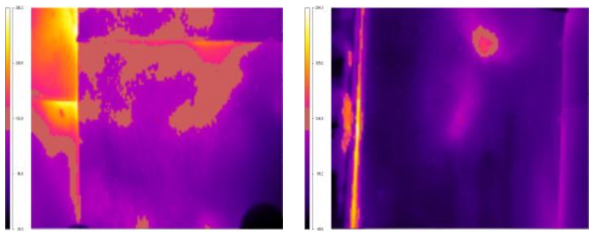

Fig. 11 Isotherms configuration at groups 1 (left) and 2 (right), through infrared registration at t_{ca} = 645 ^{0}C;
left – group 1 (with concentrator): heat recovery steam generator + fresh air afterburning;
right – group 2 (without concentrator): turbo-engine + afterburning + heat recovery steam generator

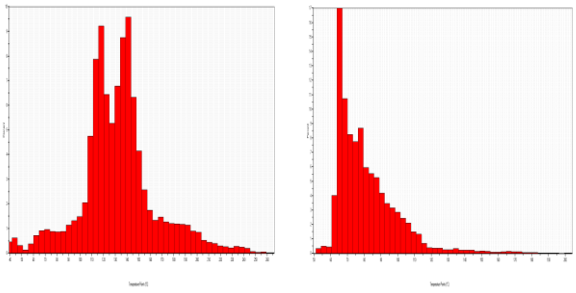

Fig. 12 Histograms at groups 1 (left) and 2 (right), through infrared registration at t_{ca} = 645 ^{0}C;
left – group 1 (with concentrator): heat recovery steam generator + fresh air afterburning;
right – group 2 (without concentrator): turbo-engine + afterburning + heat recovery steam generator

The area occupied by the isotherms in the central region (to the board of the afterburning chamber) to group 2 (without concentrator), for these operating regimes, is reduced as the gas temperature at the afterburning chamber outlet (t_{ca} increases). Unlike this situation, as noted above, the functioning of group 1 (with concentrator) the area occupied by the isotherms increases with the increase in gas temperature at the afterburning chamber outlet (t_{ca}). For group 2 (without concentrator, turbo-engine + afterburning + heat recovery version), the NO_x variation and the noise locally recorded to the burner of the afterburning installation (Fig. 6) with the burned gases temperature is given in Fig. 13. Fig. 13 shows that the NO_x emissions increase with the increase in temperature, but the values are higher than the ones in Fig. 10 (group 1 with concentrator). It is possible that the pollutant level is caused by the irregularities introduced by the gas turbine as well as by the lack of the concentrator. The noise also increases with the increase in temperature. The local noise measurements made near the burner in the second and third stage confirm the values in Fig. 9. The electro-energetic measurements are presented in Fig. 14 - 19, tracking the power variation at the electric generator terminals and the distortion coefficients variation from fundamental (THD), for current and voltage, depending on gas temperature at the afterburning chamber outlet. In the turbo-engine + heat recovery steam generator version the variation in the heat recovery steam generator load is made by variation the turbo-engine parameters. This leads to an increase in power at the electric generator terminals along with the increase in temperature at the afterburning chamber outlet (Fig. 14). In the turbo-engine + afterburning + heat recovery steam generator version the variation of the heat recovery steam generator load is made by variating the afterburning parameters leading to a quasi-constant power at the electric generator terminals (approximately 1220 kW) while the temperature at the afterburning chamber outlet increases (Fig. 15).

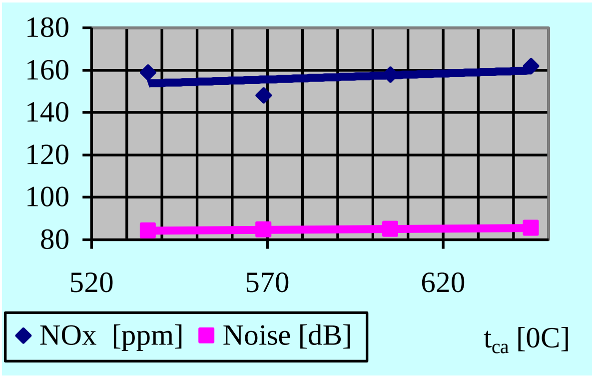

Fig. 13 NO_x and noise variation depending on temperature at the afterburning chamber outlet – group 2 (turbo-engine + afterburning + heat recovery steam generator)

In the turbo-engine + heat recovery steam generator version the value of the distortion coefficients from the fundamental (THD), for current and voltage, decrease with the increase in the temperature at the afterburning chamber outlet (Fig. 16 - 17). This decrease is more acute for the current (Fig. 16) indicating an aggravation in the electrical energy quality.

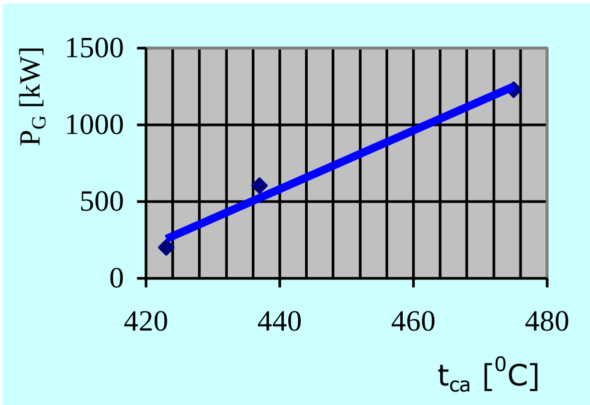

Fig. 14 Electrical power variation at electrical generator terminals depending on gas temperature at the afterburning chamber outlet, for turbo-engine + heat recovery steam generator version

In the turbo-engine + afterburning + heat recovery steam generator version the values of the distortion coefficients from the fundamental (THD), for current and voltage, remain quasi-constant while the temperature at the afterburning chamber outlet increases (Fig. 18 - 19). An analysis of Fig. 16 – 19 shows that in the turbo-engine + heat recovery steam generator version the variation of the distortion coefficients from the fundamental (THD) for current is higher than 5%. This can be seen at temperatures lower than 460 °C at the afterburning chamber outlet. The experimentations made at 2xST 18 Cogenerative Plant indicated an improvement of the flow in the burner section, particularly in the upper area, but they did not allow an appreciation of the performances deriving from the geometrical modification of the ST 18 burning module. This fact imposed new numerical simulations to indicate a new geometry for a burning module with higher performances.

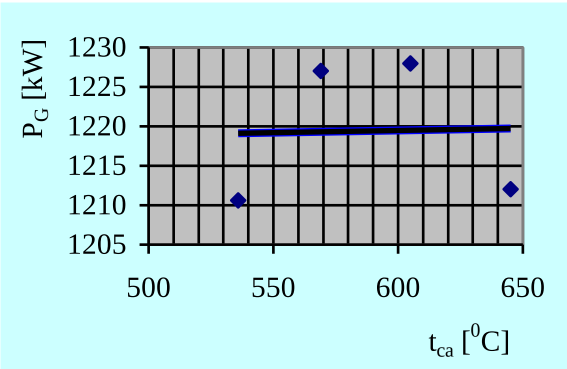

Fig. 15 Electrical power variation at electrical generator terminals depending on gas temperature at the afterburning chamber outlet, for turbo-engine + afterburning + heat recovery steam generator version

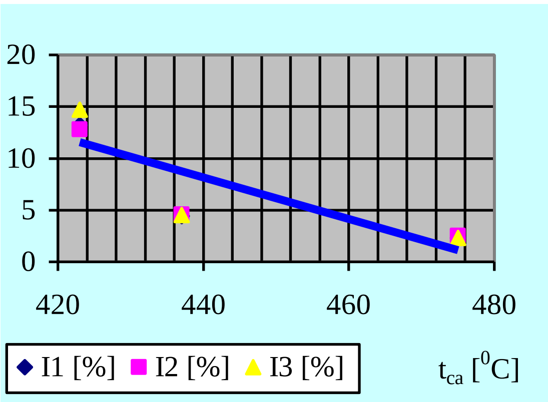

Fig. 16 Distortion coefficients variation from fundamental (THD) for current, depending on gas temperature at the afterburning chamber outlet, for turbo-engine + heat recovery steam generator version

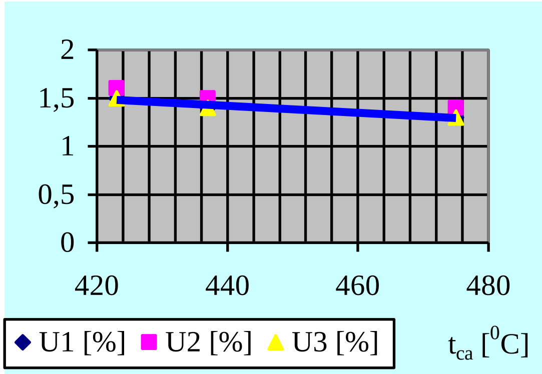

Fig. 17 Distortion coefficients variation from fundamental (THD) for voltage, depending on gas temperature at the afterburning chamber outlet, for turbo-engine + heat recovery steam generator version

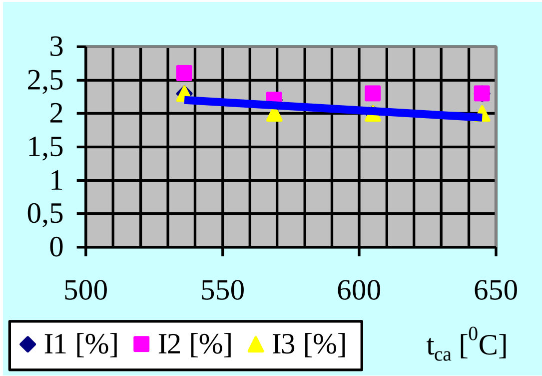

Fig. 18 Distortion coefficients variation from fundamental (THD) for current, depending on gas temperature at the afterburning chamber outlet, for turbo-engine + afterburning + heat recovery steam generator version

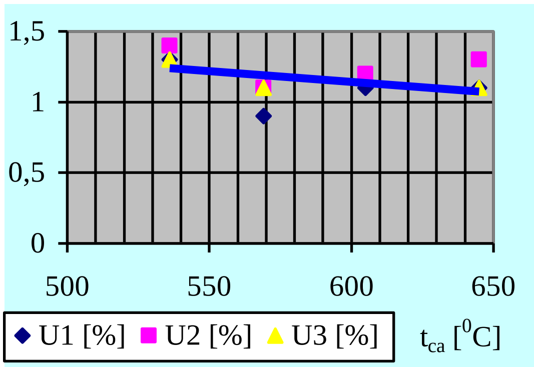

Fig. 19 Distortion coefficients variation from fundamental (THD) for voltage, depending on gas temperature at the afterburning chamber outlet, for turbo-engine + afterburning + heat recovery steam generator version

It is known that the analytical programs for gas turbines combustion chambers and afterburning installations cannot be considered quantitatively exact. Significant improvements are needed for the numerical physical models and the simulation techniques, as well as for their verification with experimental data in order to increase the approximation capacity of the current simulations.

3.2 Numerical simulations

For building the numerical model in CFD environment, based on which it was shown that the performances of the existing burner at 2xST 18 Plant can be improved, there were considered the work drawing of the burning module, transposed in 3D (Fig. 20) and the design data of the basic burning module at 2xST 18 – Suplacu de Barcau cogenerative Plant. The geometrical model was framed in a domain of 152 x 315 x 140 mm obtaining, by dislocation, a fluid domain.

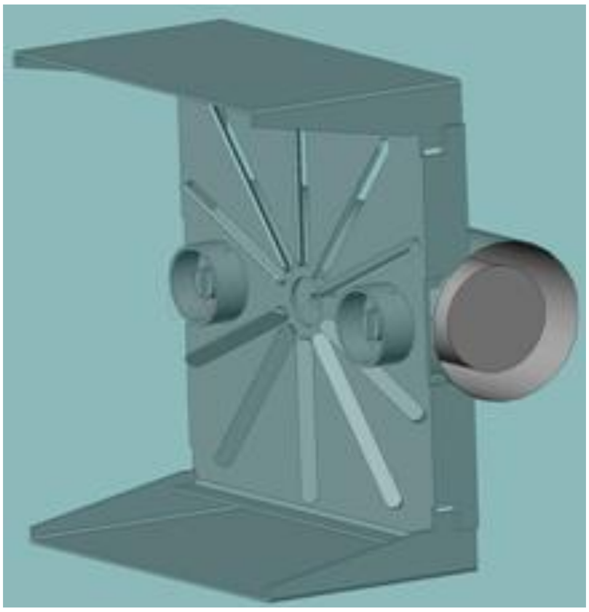

Fig. 20 Base burning module at 2xST 18 Cogenerative Plant, 3D representation

The obtained domain suffered a meshing process, very fine near the solid boundaries. This volume was introduced in a larger domain of 3549 x 152 x 315 mm meshed corresponding to operating conditions. The meshing was made with tetrahedron elements. For simulating the operation with multiple burning modules, the surfaces of the burning module were assimilated to periodic surfaces. The turbulence model used in simulations was standard k-ε. The distance from the air inlet section to the turbulence plate is 370 mm, corresponding to at least five diameters of the first met obstacle. The reference temperature at 2.5 m was set to 770 °C (1043.15 K – according to the design data of the afterburning at 2xST 18 Plant) and the error was less than 1% (7.7 °C). The numerical simulation was made in CFD environment for operation on natural gas with fresh air or burned gases from the gas generator for the basic burning module of the afterburning installation of 2xST 18 – Suplacu de Barcau Cogenerative Plant. The numerical simulations were made on a Pentium IV dual-core, 3 GHz, 4 GB computer. From the numerical and experimental data resulted that the numerical results approximated in a satisfactory manner (in the limit of ± 10%) the temperature variation in the afterburning chamber outlet section and the oxygen concentration measured at the heat recovery steam generator stack with the fuel gases volume flow (Fig. 21 – 22).

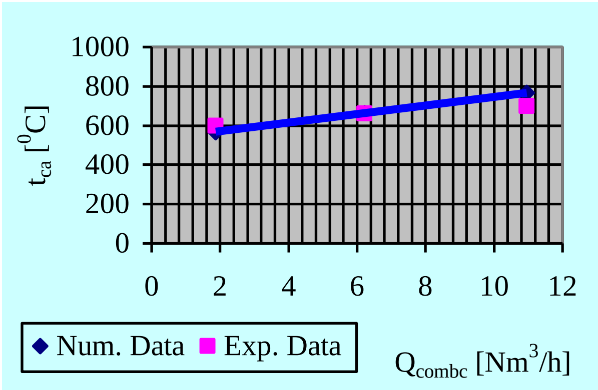

Fig. 21 Temperature variation depending on natural gas flow at the afterburning chamber outlet (Exp. Data = experimental data; Num. Data = numerical data from simulation)

Based on the experimental data obtained at 2xST 18 – Suplacu de Barcau Cogenerative Plant a new geometry of the burning module was elaborated (ST 18-R), which, in first stage was analyzed by numerical simulations in CFD environment. The new geometry of the burning module (ST 18-R) has an incorporated air (gases) concentrator and the ST 18 burning module suffered a leaning of 15° (ST 18-15 module) leading to an increased turbulence and a better mixing of the gas fuel and the comburant [4]. The CFD numerical simulations, based on the previously described numerical model, relieved a shorter flame for ST 18-R module (Fig. 23, right side) filling in a better manner the burning point compared to the old burning module ST 18 (Fig. 23, left side). The numerical simulations also indicate (Fig. 24), for the nominal afterburning operating temperature (770 °C) at the new ST 18-R burning module, NO_x emissions approximately three times lower than for the old ST 18 module.

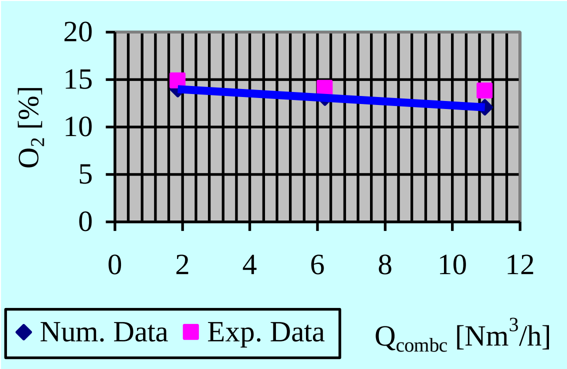

Fig. 22 Oxygen concentration variation with the natural gas volume flow at the heat recovery steam generator stack (Exp. Data = experimental data; Num. Data = numerical data from simulation)

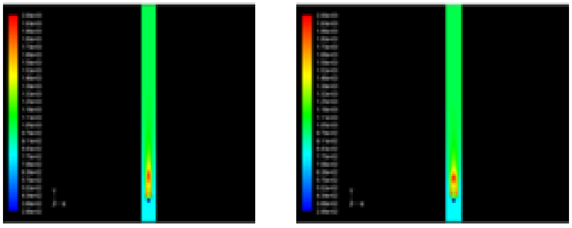

Fig. 23 Temperature variation along the afterburning chamber for ST 18 burning module (left) and ST 18-R burning module (right), operating on natural gas and exhaust gases from the turbo-engine

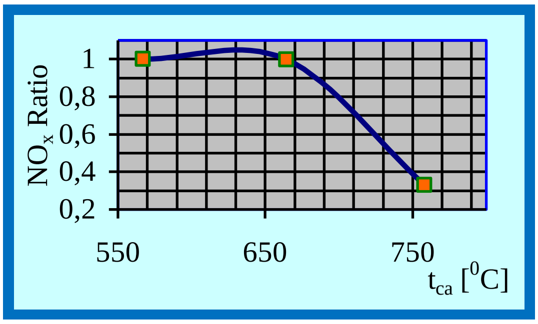

Fig. 24 The NO_x ratio variation between ST18-R and ST18 modules depending on hot gases temperature

3.2 Experimental data obtained on test bench

For the intimate research of the processes and for removing disturbing factors in the plant, there were necessary some validations on the test bench for the data obtained from 2xST 18 – Suplacu de Barcau Cogenerative Plant and the numerical results in CFD environment. For this purpose two gas fuelled burners were built, the INCDT APC 1MGN burner (Fig. 25) and the INCDT APC 1-3MGN burner (Fig. 26). The INCDT APC 1MGN burner has a thermal power of approximately 350 kW. The INCDT APC 1-3MGN burner conforms to the ST 18-R burner module geometry and is to be experimented at INCDT COMOTI Bucharest on the test bench (Fig. 27), after the test cell arrangement. The INCDT APC 1-3MGN burner will allow, on INCDT COMOTI Bucharest test bench, testing individual ST 18 burning modules or multiple modules (maximum three ST 18, at approximately 1MW thermal power) but it can be adjusted for other burning modules geometries in the ST 18 modules range.

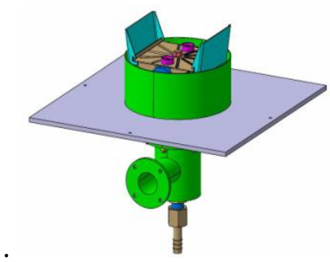

Fig. 25 INCDT APC 1MGN burner with ST 18-15 module - 3D representation

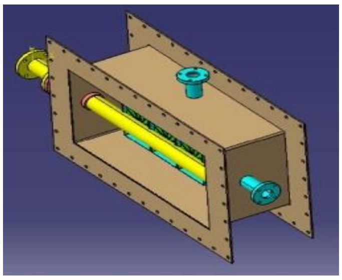

Fig. 26 INCDT APC 1-3MGN burner - 3D representation

Fig. 27 Command room and the turbo-engine in the INCDT COMOTI Bucharest test cell

The INCDT APC 1MGN burner allows testing only one ST 18 burning module (or leaned at 15°) but it can be adapted to other burning modules geometries framed in the ST 18 range. The natural gas is introduced through the nozzle in the lower area and the combustion air is introduced through the flanged lateral lead-in. Experimentations of the INCDT APC 1MGN burner with the ST 18 burner module (or leaned at 15°) were made on the test bench at University Politehnica of Bucharest (UPB), Classic and Nuclear Thermo-mechanic Equipment Department (Fig. 28).

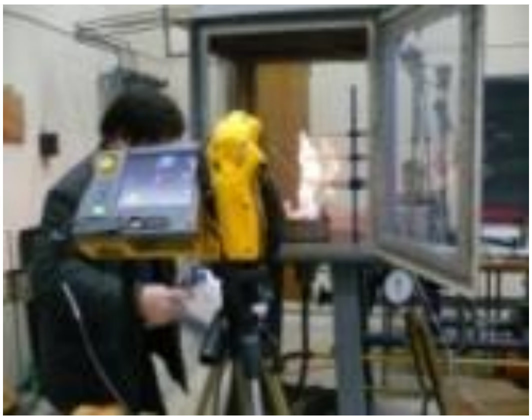

Fig. 28 Testing the INCDT APC 1MGN burner in the UPB test cell

The testing for the two types of burning modules was made on natural gas (0.5; 0.7 and 0.88 m^3/h). The experimentations were made in a parallelepiped enclosure (890 x 890 x 990 mm), continued in the upper area with a truncated pyramid connected to the exhaust gases stack. The walls of the enclosure are built in glass allowing monitoring the flame from all four flanks, one flank being provided with an access door (Fig. 28). The connection of the burner to the natural gas network was made through a flexible pipe while the one to the air fan consisted in a flanged detachable assembly. The placement of the burner in the enclosure was made with the help of a position plate fasted with bolts (Fig. 25, 28). The emission measurements were achieved with a MRU – Analyzer Vario Plus Ind. gas analyzer while for the noise measurements a 01dBMetravib SOLO sound meter was used, installed in the upper area of the enclosure. The exterior superficial temperature profile was determined with the help of a infrared elevation camera – Ti45FT Fluke. In order to avoid errors in the displayed temperature profile caused by the glass walls, the flame was visualized with the enclosure door open (Fig. 28). The emissions and noise measurements at the three values of the gas volume flow were made with the enclosure door closed. The measurements of the temperature distribution was made with three thermocouples (tip PtRh30% - PtRh46%) placed on a bay in the enclosure, along the flame development length. The numbering of the thermocouples starting from the base to the peak was: T_{FL1} , T_{FL2} si T_{FL3}. Fig. 29 presents the CO and NO_x ratios variation corresponding to ST 18-15 and ST 18 modules with the natural gas volume flow. For the 0.88 m^3/h natural gas volume flow a decrease of over 30% in NO_x emissions occurs for the ST 18-15 module compared to ST 18 module.

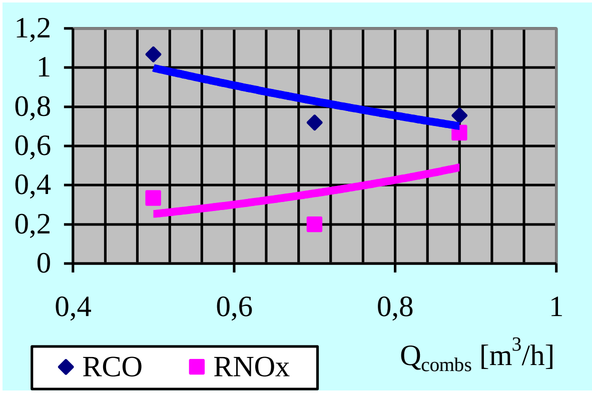

Fig. 29 The CO and NO_x ratios variation corresponding to ST 18-15 and ST 18 modules depending on natural gas volume flow

The shown CO and NO_x ratios variation corresponding to the ST 18-15 and ST 18 modules in the volume flow range can be approximated by the following equations:

$$R_{CO} = 1,5889(e^{-0,9297Q_{combs}}) \quad (1)$$

$$R_{NOx} = 0,1055(e^{1,7473\,Q_{combs}}) \quad (2)$$

The flame temperature distribution of the ST 18-15 module is more homogenous and the increase in temperature along the flame is slower, as shown in Fig. 30 and 31. This also results from Fig. 32 – 34, the infrared recordings for the ST 18 module (left side) and the St 18-15 module (right side). With the increase in natural gas volume flow the areas occupied by the high temperature isotherms also increase significantly for the ST 18-15 module. Compared to ST 18 module, the flame fills the burning point in a better manner, it shortens, the temperature distribution is more homogenous and the CO and NO_x emissions decrease. The noise recordings (Fig. 35) show that the ST 18-15 module has slightly higher values than the ST 18 as a result of the increased turbulence. This phenomenon can be observed particularly at high volume flows (0.88 m^3/h).

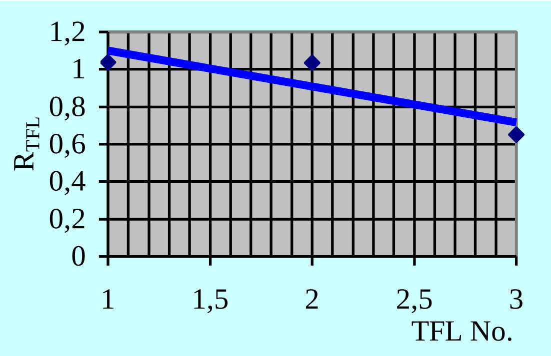

Fig. 30 Temperatures ratio variation in the flame (for T_{FL1} , T_{FL2} si T_{FL3}), corresponding to ST 18-15 and ST 18 modules, at $Q_{combs} = 0.5$ m^3/h

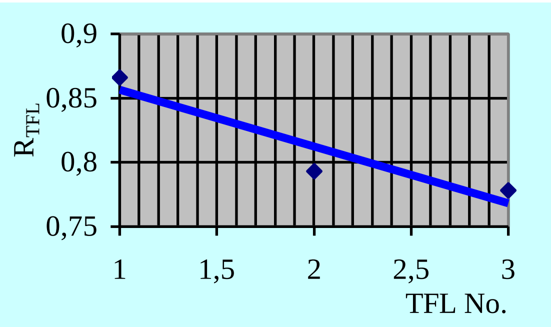

Fig. 31 Temperatures ratio variation in the flame (for T_{FL1} , T_{FL2} si T_{FL3}), corresponding to ST 18-15 and ST 18 modules, at $Q_{combs} = 0.88$ m^3/h

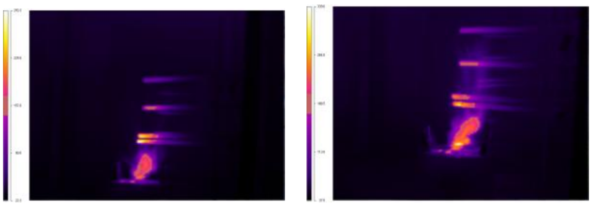

Fig. 32 Isotherms in infrared recording for ST 18 (left) and ST 18-15 (right) modules, at $Q_{combs} = 0.5$ m^3/h

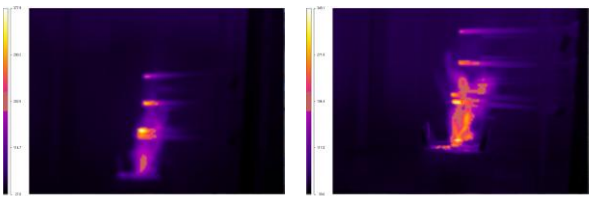

Fig. 33 Isotherms in infrared recording for ST 18 (left) and ST 18-15 (right) modules, at $Q_{combs} = 0.7$ m^3/h

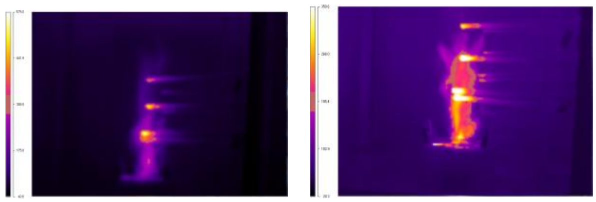

Fig. 34 Isotherms in infrared recording for ST 18 (left) and ST 18-15 (right) modules, at $Q_{combs} = 0.88$ m^3/h

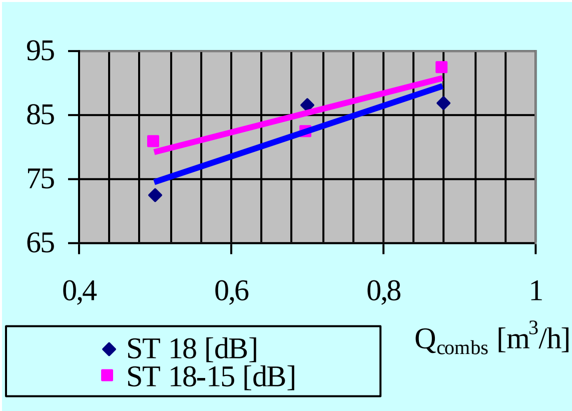

Fig. 35 Noise variation corresponding to ST 18-15 and ST 18 modules, depending on natural gas volume flow

The researches accomplished until now have shown that the ST 18-15 module proves to be superior to the ST 18 module, the numerical simulation data being confirmed by the experimental ones obtained on test bench.

4 Conclusions

1. The analysis in CFD environment of the afterburning from the 2xST 18 – Suplacu de Barcau Cogenerative Plant has shown that the performances can be improved by redistributing the air in the burner with the help of a concentrator. The concentrator was installed to group 1 before the afterburning.
2. After installing the concentrator, new researches have been made at 2xST 18 – Suplacu de Barcau Cogenerative Plant concerning the afterburning installation at different operating regimes in terms of emissions, noise, exterior superficial temperature profile and energy quality.
3. Higher NO_x emissions were recorded at group 2 operated in cogenerative regime, where there is no concentrator installed. It is possible that additional irregularities occur from the gas generator.

4. The noise locally recorded in the afterburning area shows a slightly increase at group 2 with the increase in the burned gases temperature. The noise values in the afterburning area were commonly in the 80 – 85 dB range.
5. At group 1 the areas occupied by the isotherms increase with the increase in temperature in the afterburning chamber outlet section in a large operating regimes range.
6. At low loads for the case of the turbo-engine operating with the heat recovery steam generator the distortion coefficients variation from the fundamental (THD). for current, is higher than 5%.
7. Based on experiments the burner of the afterburning installation was redesigned for a new burning module geometry (ST 18-R). The numerical simulations have shown approximately three times lower NO_x emissions for the new burning module (ST 18-R) compared to the old one (ST 18).
8. Test bench experimentations were made for an intimate research of the processes and for eliminating the disturbing factors from the experimental data obtained at the cogenerative plant. Tests were made for a modular burner on natural gas and air in terms of emissions, noise and temperature profile for the ST 18 and the ST 18-15 burning modules.
9. In the experimented natural gas volume flow (0.5 – 0.88 m^3/h) with air results a decrease of over 30% in NO_x emissions for the ST 18-15 module compared to ST 18. The flame fills better the burning point, it shortens, the temperature distribution is more homogenous and the CO and NO_x emissions decrease.
10. The analysis of the numerical and experimental results in terms of emissions, noise and temperature profile have shown that the ST 18-15 module is superior to the ST 18, the numerical results being validated by the experimental ones.
11. The researches will continue with test bench experiments for natural gas and burned gases (fresh air) for individual and multiple burning modules. The burner optimized on test bench will also be experimented in industrial conditions.

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