

ISSN br. 0354-8651



List Saveza energetičara  
Broj 1-2 / Godina XIX / Mart 2017.  
UDC 620.9

# energija

■ ekonomija ■ ekologija




# ENERGETIKA 2017

# ENERGETIKA 2017.

## XXXIII međunarodno savetovanje

 energija

 ekonomija

 ekologija

# ENERGETIKA 2017.

Pokrovitelj savetovanja

Ministarstvo rudarstva i energetike,  
Ministarstvo prosvete, nauke i tehnološkog razvoja,  
Ministarstvo poljoprivrede i zaštite životne sredine,  
Ministarstvo privrede  
PKS, JP EPS, NIS a. d., JP EMS, JP Srbijagas



**SAVEZ ENERGETIČARA**

Adresa: 11000 Beograd, Dečanska 5

Telefon: + 381 11 32 26 007

E-mail: [savezenergeticara@eunet.rs](mailto:savezenergeticara@eunet.rs)

[www.savezenergeticara.org.rs](http://www.savezenergeticara.org.rs)

ZBORNIK RADOVA

Zlatibor, 28.03. - 31.03.2017

## ORGANIZACIONO - PROGRAMSKI ODBOR

**Predsednik:** Prof.dr Milun Babić, Mašinski fakultet u Kragujevcu

**Sekretar:** Nada Negovanović, sekretar Saveza energetičara

### Članovi:

- Dr Jean Rizzon, Mitsubishi Hitachi Power System Europe GmbH  
Dr Patrick Weckes, Mitsubishi Hitachi Power System Europe GmbH  
Jovica V. Milanović, The University of Manchester, Manchester  
Christian Kissling, HEAD OF Sales, MHPSE, GER  
Zoltán Teuber ERC Technik GmbH Germany  
Prof.dr Adriana Sida Manea, Politehnica-Universitety of Temisoara, Romania  
Dr Ivan Souček, Ph. D., Prague Institute of Chemical Technology, Czech Republic  
Prof. dr Zoran Rajić, državni sekretar  
Prof. dr Miloš Banjac, pomoćnik ministra  
Prof. dr Branko Kovačević, predsednik Nadzornog odbora JP EPS  
Prof. dr Aleksandar Gajić, Mašinski fakultet Beograd  
Dejan Popović, Nadzorni odbor JP EPS  
Prof. dr Dečan Ivanović, Mašinski fakultet Podgorica  
Prof. dr Zdravko N.Milovanović, Mašinski fakultet Banja Luka  
Prof. dr Valentino Stojkovski, Faculty of Mechanical Engineering – Skopje, Institute for Hydraulic Engineering and Management of Water  
Prof. dr Predrag Popovski, Faculty of Mechanical Engineering, Skopje  
Goce Vasilievski, Rudarski institut, Skopje  
Atanasko Tuneski, Faculty of Mechanical Engineering, Skopje  
Aleksandar Levkoski, ELEM Macedonian Power Plants - Skopje  
Prof. dr Vladimir Rajs, Fakultet tehničkih nauka Novi Sad  
Doc. dr Željko Đurišić, Elektrotehnički fakultet Beograd  
Dr Tatjana Luppova, Rusija  
Prof. dr Nebojša Petrović, Mašinski fakultet u Beogradu  
Prof. dr Nikolaj Ostrovski  
Prof. dr Vlatko Chingoski, Faculty of Electrical Engineering, University "Goce Delcev" Macedonia  
Prof. Daniela Marasova, CSc. Technical university of Kosice Faculty of Mining, Ecology  
Prof.dr Беляков Алексей Васильевич – Российская Федерация  
MSc. Ljupco Davcev, Institute for Standardization of R.Macedonia-ISRМ, Skopje  
Olga Stavskaya, Lead Engineer JSC «ZiO-COTES», Russian Federation  
Prof. dr Nebojša Mitrović, dekan Tehničkog fakulteta u Čačku  
Prof. dr Zoran Jovanović, dekan Elektrotehničkog fakulteta u Beogradu  
Prof.dr Radivoje Mitrović, dekan Mašinskog fakulteta u Beogradu  
Ljubo Mačić, Predsednik Agencije za energetiku Srbije  
Prof. dr Ozren Očić, Faculty of International Engineering Management  
Dr Miodrag Arsić, IMS Beograd  
Prof. dr Željko Despotović, IMP  
Dr Miroslav N.Malobabić, izvršni direktor JP Srbijagas  
Prof. dr Pavlović Vladimir, Rudarsko-geološki fakultet  
Prof. dr Nenad Đajić, glavni i odgovorni urednik časopisa ENERGIJA



Vlatko CINGOSKI, Doc. EE  
Faculty of Electrical Engineering, University "Goce Delcev" – Stip, Macedonia  
Dimitar TANURKOV, MSc. ME  
JSC "Macedonian Power Plants" – ELEM, Skopje, Macedonia  
Dimitar TANURKOV, MSc. ME  
SEVER-MAK, Skopje, Macedonia

UDC: 621.18:621.311.22 (497.17)

## Extensive Boiler Rehabilitation at TPP Bitola - Lessons Learned

### ABSTRACT

*Thermal Power Plant (TPP) Bitola is the largest lignite-based TPP in the Republic of Macedonia with three units put into operation in 1982, 1984 and 1988, respectively. All three units have already operated more than 200.000 hours each, therefore they are far beyond their normal life expectancy. Thus, a large-scale rehabilitation program including extensive boiler rehabilitation of all three units, lignite supply chain modernization, steam turbines, generators and control system modernization, etc. was initiated. During rehabilitation, a special attention was paid that after the rehabilitation, all three units become fully compliant with the EU Directive for LCP Plants (EU Directive 2001/80/EC). In this paper, the authors present brief description of the extensive boiler's rehabilitation program, the implemented technology, and some lessons learned during the process of rehabilitation. In addition, the achieved rehabilitation results are also given and discussed.*

**Key words:** coal-fired thermal power plants, rehabilitation, combustion boilers, EU Directive 2001/80/EC

### ОПСЕЖНА РЕХАБИЛИТАЦИЈА КОТЛОВА У ТЕ БИТОЉ – НАУЧЕНЕ ЛЕКЦИЈЕ

Проф.д-р Влатко Чингоски\*

Електротехнички Факултет, Универзитет „Гоце Делчев“ – Штип, Македонија

М-р Димитар Танурков\*\*

АД Електрани на Македонија, ЕЛЕМ, Скопје, Македонија

М-р Коста Папастеревски\*\*\*

Север-Мак, Скопје, Македонија

### АБСТРАКТ

*Термоелектрана (ТЕ) Битољ је највећа ТЕ у Републици Македонији која користи домаћи лигнит са три јединице пуштене у рад 1982, 1984. и 1988. године. Све три јединице већ раде више од 200.000 сати сваки, према томе они су далеко преко њиховог нормалног животног века. АД „Електрани на Македонија“ су неминовно покренуле програм рехабилитације великих размера на све јединице, укључујући рехабилитацију котлова, модернизацију ланца снабдевања лигнитом, парне турбине, генератора и модернизацију контролног система, итд. Током рехабилитације, особита пажња је била посвећена да након рехабилитације, све три јединице буду потпуно у складу са директивом ЕУ 2001/80/ЕС за велике електрана које раде на бази сагоревања угља (Large Combustions Power Plants).*

*У овом раду, аутори представљају кратак опис опсежним радова на рехабилитацији котлова термоелектране, опис примењене технологије, као и неке лекције научене током извођења програма рехабилитације. Поред тога, у раду су приказани и остварени резултати рехабилитације уз одговарајућу дискусију истих.*

**Кључне речи:** термоелектране на угљ, рехабилитација, котлови, ЕУ директива 2001/90/ЕС

## 1. INTRODUCTION

Almost 80% of whole electricity production in the Republic of Macedonia country depends on burning local coal while Thermal Power Plant (TPP) Bitola is the largest TPP which utilizes domestic lignite [1]. After closing of the TPP Oslovej in 2013 due to lack of suitable quantity and quality of the local lignite, TPP Bitola becomes the solely coal-fired TPP in the country. With its annual electricity production estimated at around 4,600 GWh, TPP Bitola has a paramount importance for stability and security of the electricity market within the Republic of Macedonia, and Macedonian power sector became extremely vulnerable and dependable on its proper operation.

TPP Bitola plant is located in the southern part of the country near the city of Bitola. It consists of three identical coal-fired power units that utilize locally-mined lignite. Originally, the power plant had three 210 MW units commissioned in 1982, 1984 and 1988, respectively. In 1994, all three units had capacity upgrade from the original 210 MW to 225 MW by means of increase of the steam flow. The average lignite consumption of Bitola TPP, depending on the lignite quality is around 6,000,000 tons/year while the average net electric efficiency is about 31-32%, which is rather low compared with the modern combustion type TPP which utilize the Best Available Technology (BAT) [2].

Put into operation back in the 1980s, all three units have already operated more than 200.000 hours each. Working beyond their normal life expectancy, a large-scale rehabilitation program was compulsory mostly to prolong their operational life. Therefore, in 2008 the JSC Macedonian power plants (ELEM) who is the owner and operator of the plant, made important decision to initiate rehabilitation on all three units in the period of three consecutive years [3], [4]. The main purpose of the initiated rehabilitation program was to identify the scope of the rehabilitation works for each power plant separately, that will extend lifetime of the main equipment, improve energy efficiency and overall unit performance as well as reduce negative environmental impacts. All of that had to be done taking into account the locally available lignite reserves and potential fuel supply schemes. The rehabilitation program should at least extend the overall life-extension of each unit for min 120,000 hours that corresponds to about 15 years of additional operation.

In this paper, the authors present in brief the whole process, starting from the investigation of the remaining operational life of the existing equipment, definition of the total scope of works, selection of the best offered rehabilitation scheme, do the rehabilita-

tion works and compare the expected with achieved rehabilitation results. The main accent was paid to the boiler rehabilitation as the heart of each power unit. However, the rehabilitation program was additionally extended to other, more or less crucial parts, such as coal mills, water and air feeding pumps, replacement of existing with new modern and low NOx burners, full rehabilitation of the generators, and finally, introduction of modern control system that could enable inclusion of TPP Bitola units in the group of power plants that could provide auxiliary services to the Macedonian Power System Operator (PSO). The authors close this paper with a brief presentation of the results and lessons learned during this extensive rehabilitation program.

## 2. PREPARATION PHASE

Performing extensive rehabilitation on the units that are so much important for our country's power supply is complex, difficult, and highly sensitive task. Having this in mind, for the most important task was to perfectly execute the initial step, the so-called preparation phase of the rehabilitation program. The most important challenges during this phase were:

- Estimated, as close as possible, the present status of the existing major equipment and to estimate how long could these equipment be able to properly operate in the future,
- Analyze the past operation of each unit and allocate the most critical points that were main source of unexpected outages at least for the last five to ten years,
- Analyze activities that were usually done during the regular yearly maintenance period for each unit also for the last five to ten years period,
- Perform analysis of similar rehabilitation programs already done to similar power units worldwide and investigate the actions, achieved improvements and operational results,
- Discuss with the major equipment producers about their latest experiences and improvements in their coal-fired unit design program and see if they could be applicable to our old plants,
- Investigate the latest EU Directives in respect to older combustion type power plants, especially EU LCP Directive 2001/80/EC – the EU Directive for Large Combustion Plants, regarding emission reductions and eligibility that our power plants after rehabilitation could get full approval from the EU Energy Community in respect of air emission limits and standards,
- Make financial estimation how expensive this rehabilitation program could be and compare

these costs with costs for performing any other programs that could provide us with the similar results on a long run, such as decomposition of the existing plants and their replacement with a new contemporary units, refueling of the existing ones with other fuels, most probably natural gas, etc.,

- Define an appropriate rehabilitation plan and schedule that could provide enough time each unit to be under rehabilitation program and out of operation and not aggravate the general power production program in the country. Finding suitable timing and replacement for the unproduced electricity during rehabilitation period from other power generation sources and under which cost,
- Assemble a project unit or team of qualified personal from within the company, and if necessary, engage outsourcing staff that would closely monitor the whole rehabilitation process,
- Do a SWOT analysis for the rehabilitation program and select any mitigation activities that might become necessary in case of occurrence of unexpected problems during the implementation.

The above extensive list confirms that only after careful consideration of those issues one could start with rehabilitation program. For combustion type power plants, the critical issue is the combustion boiler and the piping system inside the boiler. Almost 90% of all defects are directly or indirectly connected with pipe burst inside the boiler due to narrowing the thickness of the pipes and/or uneven heating of the pipes. Thus, the quality of the piping system inside the boiler is of large importance. Therefore, a study of the piping system for all three units in TPP Bitola was done before setting the scope of works that should be part of the boiler rehabilitation work [5], [6].

As a result of the boilers and boiler's piping examination, on one side, and having into consideration the existing BAT for LCP plants and some already performed modernization on similar TPP [7], on the other side, three possible approaches for sustainable extension of the operational life of Bitola TPP were initially considered:

1. Performing large-scale rehabilitation program of the existing units including boiler rehabilitation, lignite supply chain modernization, modernization of steam turbines, generators and control system, desulphurization, etc.,
2. Replacement of all three units with completely new and modern super-critical power units, fully compliant with the BAT for LCP plants, or

3. Mixed approach, rehabilitation of some of the existing units and adding some new and modern super-critical power units.

For a country that has wide margin of available power units in the pipeline that could be started up at any time if it is necessary regardless of the production cost that they have, the execution of any rehabilitation program is much easier. However, in a country like Macedonia, which has very limited, or especially in the winter period, no margin at all and where any of its power plants has special place in the country's power generation plan, taking a major rehabilitation program for such important power plants is high risk step.

### 3. CONSTRAINS AND INVESTIGATION OF POTENTIAL ALTERNATIVE SOLUTIONS

As mentioned above, the main question for the power plant's owner was: *How to provide sustainable extension of the operational life of TPP Bitola with least-cost investments adhere to the EU Environmental Directives for the expected period of locally-mined lignite?* To answer the above question, several constrain factors had to be investigated:

1. The security of electricity production, not only after rehabilitation, but also during the process of rehabilitation/replacement of existing units with new modern units,
2. The estimated life expectance of the local lignite mines, i.e. estimate the amount of available and economically feasible quantities and qualities of lignite that could be extracted from the local mines and utilized for electricity production at TPP Bitola,
3. The amount of total investment necessary for realization of whole project, either rehabilitation of the existing units, or decommissioning of them and replacement with new units,
4. The achievable environmental improvements with large-scale rehabilitation program, and to compare these achievable values with prescribed approved values for each pollutant by the respective EU Directives for such thermal power plants.

#### 1.1 Security of Electricity Supply Constrain

The first crucial step before even thinking of having a rehabilitation program was setting the maximum period that Macedonian power network could sustain with a single power unit out of the grid. This period was set to be 120 days per year the most. These results in two major conclusions: (1) if rehabilitation is considered, only one unit per year could be rehabilitated, and (2) only those companies that guarantee suc-



successful execution of the whole requested and offered scope of works within maximum time period of 120 days, could be eligible as potential operators. This, to adhere to the above two major preconditions, a good and precise schedule for production of the equipment, timely delivery of the parts to the site and well organized field work were necessary.

### 1.2 Life Expectance of Local Lignite Mines

TPP Bitola uses the locally excavated low-calorie lignite from two existing lignite mines in the vicinity of TPP Bitola, one is the older mine Suvodol with estimated reserves of lignite of about 20 million tonnes, and the newly opened lignite mine Brod-Gneotino with estimated reserves of about 30 million tonnes. In addition, there are activities for opening the third one, the so-called Lower Lignite Layers (LLL) below the existing surface mine Suvodol which according to the performed studies could provide additional 50 million tonnes reserves of lignite. With suitable combination and homogenization technology, these three lignite mines could provide approximately 100 tonnes of lignite enough for stable electricity production in the coming 15-16 years with annual lignite consumption of approximately 6.0 million ton/year [8].

Accordingly, it is obvious that construction of a new coal-fired unit in TPP Bitola could not be fully justified since the operational life of new units is between 25 and 30 years, a period for which local lignite mines cannot secure stable lignite supply. Further investigations might give some optimistic figures if one takes into account that new units could have larger net efficiency (*app.* 36-38%) than the existing ones (31-32%). This 5% net efficiency increase could provide lignite savings per year (*app.* 320,000 tonnes/year), or prolongation of operational life in total for the investigated 15 years for additional 4-5 years, that might be valuable only in case that the investment in the new units would be economically justified over the investment made in the rehabilitation of the existing units.

### 1.3 The Amount of Investments

The amount of the investments and the possibilities to obtain them under most favourable financial conditions was a crucial issue, too. TPP are not favourable investments projects for the major international financial institutions (*EBRD, IBRD, KfW, EIB, etc.*). Providing loans for coal-fired TPP is very challenging and highly unsecured task, due to their unfavourable environmental footprint – large emissions of CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>, dust particles, etc. It is more likely to obtain suitable loans for modernization, rehabilitation

and environmental improvements of the older TPP units, than for construction of a new, even BAT TPPs. Additionally, new units usually come with BAT such as CCS (*Carbon Capture Storage*), low NO<sub>x</sub> burners, desulphurization units, electrostatic precipitators, etc. The additional increase of the investments on one side, and in parallel, decrease of the unit's efficiency due to increasing the electricity self-consumption of the plants, on the other side, very often is not the best solution.

### 1.4 Environmental constrains

TPP Bitola is one of the largest concentrated pollutants in the Republic of Macedonia regarding the emissions of the Green-house Gasses (GHG), in particular, NO<sub>x</sub>, SO<sub>x</sub> and dust particles. The current emission rates for all three pollutants are several times above the admissible rates by the LCP EU Directive [7] and the admissible rates of a new and modern large combustion power plant burning lignite and utilizing the BAT. According to the results of recently done study [9], the average amount of NO<sub>x</sub> emissions at TPP Bitola were little above Directive. However, since after 2016 the admissible amount drops down to only 200 mg/Nm<sup>3</sup>, with future tendency to go down as low as 50 mg/Nm<sup>3</sup>, points into direction that the average value had to be at least halved. The situation with emissions of SO<sub>x</sub> was even worst. From the average value of 2,700 mg/Nm<sup>3</sup>, it was necessary to decrease the emission rates initially to 400 mg/Nm<sup>3</sup> (*almost 7 times*), and beyond 2016 further down to 200 mg/Nm<sup>3</sup>, or almost 14 times. Similar results were observed in case of emissions of dust particles, where in order to adhere to LCP Directive before 2016 the amount of dust particles, emissions should be reduced 6 times, from existing 300 mg/Nm<sup>3</sup> to admissible 50 mg/Nm<sup>3</sup>. Beyond 2016, the situation could be even tougher, and the reduction rates could be lower even 10 times down to only 30 mg/Nm<sup>3</sup>. All these requirements are difficult and expensive to achieve. However, the EU Directives are must for anyone who would like to continue with electricity generation using coal-fired power plants and in the same time to pursuit accession with other EU, and does electricity trade within EU borders.

## 4. BOILER REHABILITATION – SCOPE OF WORKS

The full scope of rehabilitation could be divided into three main parts:

1. Rehabilitation of boilers including rehabilitation of coal mills, water and air supply and coal burners,

2. Rehabilitation of the generators including static exciters and voltage regulation, and
3. Rehabilitation of the control system for control and monitoring of the power unit operation.

In this paper only the first part, the rehabilitation of unit boilers would be discussed.

### 1.5 Existing boiler data

The existing boilers at TPP Bitola were classical ZIO-Podolsk P-65 model boilers as shown in Fig. 1. The P-65 steam boiler cross-section has T-letter shape, and consists of three vertical parts mutually connected with horizontal gas duct. The central part is furnace and has octagonal shape. Upper part of the furnace is tightening and converts into quadrilateral. Walls of furnace are separated into three different parts such are low, middle and high radiation part. The combustion temperature is approximately 1400°C and the temperature of gases in feedback chamber is 800°C. The amount of coal combustion is between 238 and 360 t/h. On the level 14,355 mm and 17,065 mm of the front and the back part of the furnace, four fuel start-up oil burners are placed, all with burning capacity of 2 ton/h. The mill fan starts working when temperature of feedback chamber is between 420°C and 450°C, while the under pressure in furnace upper part is between 30 and 50 Pa. The oxygen level in economizer can't be lower than 5%. In the other two parts there are two parts: primary and secondary steam super heaters and water re-heaters – economizers. The

boiler's basic parameters are: production of maximum of 700 t/h steam with primary steam temperature of 545°C at primary steam pressure of 140 bars. The boiler efficiency is 85% burning coal with caloric value of 7699 KJ/kg.

### 1.6 Brief description of modernization and planned rehabilitation activities

As defined, the main target of the rehabilitation process was permanent, effective, safe and secure boiler exploitation for additional 120,000 hours, with the following guaranteed characteristics:

- Coal caloric value in the range between 6,179 – 8,101 KJ/kg,
- Steam production: 700 t/h, with exploitation of 5 mills, with coal caloric value given before,
- Primary steam temperature: 545°C;
- Primary steam pressure: 140 bar;
- Secondary steam temperature: 545°C;
- Water supply temperature: 252°C;
- Guaranteed variation of steam boiler working parameters should be ±1.5%,
- Permanent, effective, safe and secure boiler exploitation without break-down,
- Increasing of boiler's efficiency,
- Extend the lifetime on the heating surfaces of the boiler and made suitable protection,
- Reduce the gas outlet temperature, and

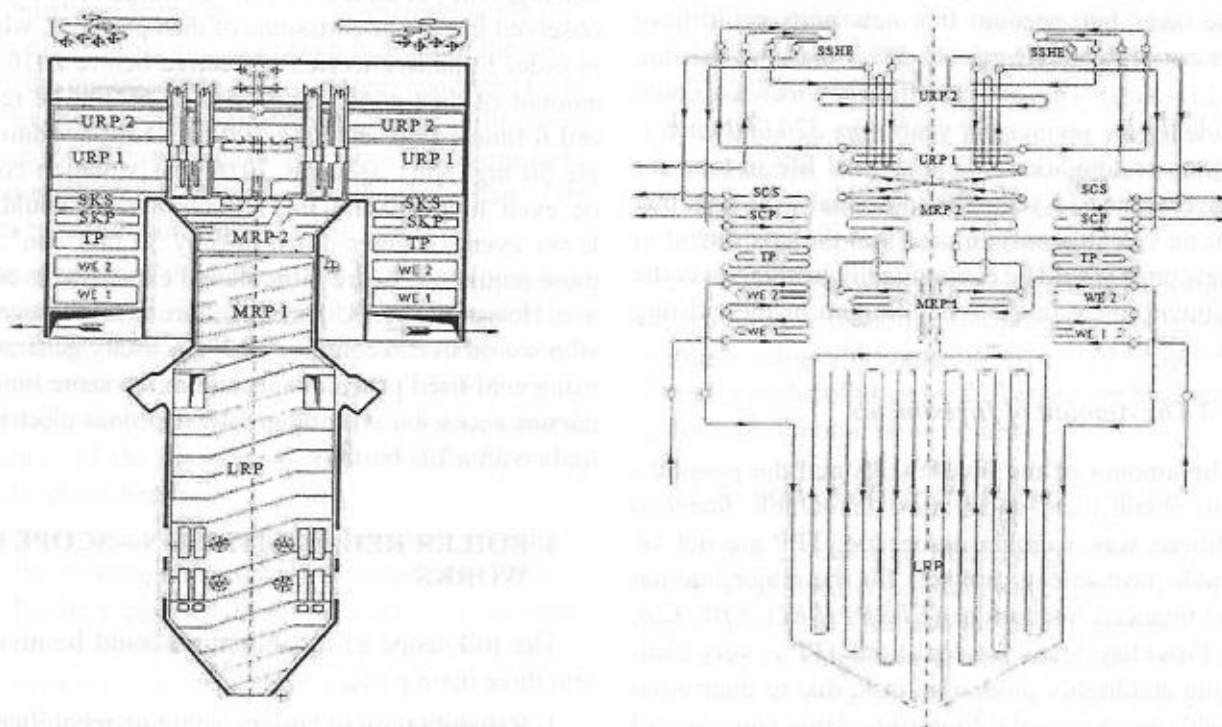


Fig. 1. - The schematic disposition of a) the boiler heating surfaces, and b) the schematic disposition of the line of primary steam.



- Reduction of NO<sub>x</sub> emission and improve environment norms in according with EU directive after 2016.

### 1.7 The selected rehabilitation scenario

Using the international competitive procedure, the German company Babcock Borsig Steinmüller (BBS) was selected as the best evaluated bidder for boiler rehabilitation, among else the following activities:

- Changing of the main boiler components in the combustion area and the coal dust burners with adequate pulverized coal burners,
- Replacement of the coal classifiers and pipes of coal dust,
- Installation of two air levels of combustion, the so-called Over Fire Air (OFA) levels,
- Installation of hot tubes and burners for initial ignition, for primary, secondary and air burnings,
- Revitalization of the air pre-heaters are the complete replacement of hot metal baskets,
- Accordingly, reconfiguration and adaption of a new Digital Control System (DCS) with adequate measuring devices, sensors and actuators.

The BBS guaranteed the following as a result of the offered rehabilitation activities:

- NO<sub>x</sub> emissions  $\leq 200 \text{ mg / Nm}^3$  at 6% O<sub>2</sub> in dry smoke output only with primary measures, at maximum nitrogen content in fuel  $\leq 0.46\%$ ,
- CO emissions  $\leq 200 \text{ mg / Nm}^3$  at 6% O<sub>2</sub> in dry smoke output,
- Steam temperature of 545°C in the range between 70 and 100% of the max boiler power,

- Boiler efficiency  $> 86.5\%$  at 100% load and quality of coal set by the investors data,
- Availability  $> 91\%$  for the first 12 months after modernization, and
- Availability  $> 95\%$  for the next 12 months and beyond.

#### 1.7.1 Extension of the life expectancy

The boiler is the dominant part in the whole technological process of power generation in the combustion power plants because it produces required quantity and quality of the steam to drive a steam turbine. As a result of different number of operational hours and the status of the equipment at each of all three units, some variations were necessary. The major rehabilitation tasks are schematically given at various areas of the boiler at Fig.2. As shown the major rehabilitation was scheduled for the lower burning area of the boiler (see Fig. 3), where beside installation of new Low-NO<sub>x</sub> burners at new locations, a new and improved design of the burner's openings is proposed together with different angles of coal dust supply from the mills to the boiler at angles of  $-10^\circ$ ,  $-9^\circ$  and  $-25^\circ$ , respectively, in order to achieve stable and evenly distributed fireball within a diameter of approximately 2 m (Fig. 4). The amount of steam that could be providing with (n-1) mills, strongly depends on the quality of the coal used, and according to the simulation, the rehabilitated boiler could generate between 60 and 100% of the rated amount of steam with (n-1) mills for minimum caloric value of the supplied coal of 6.18 MJ/kg or 1,480 kcal/kg (see Fig. 5).

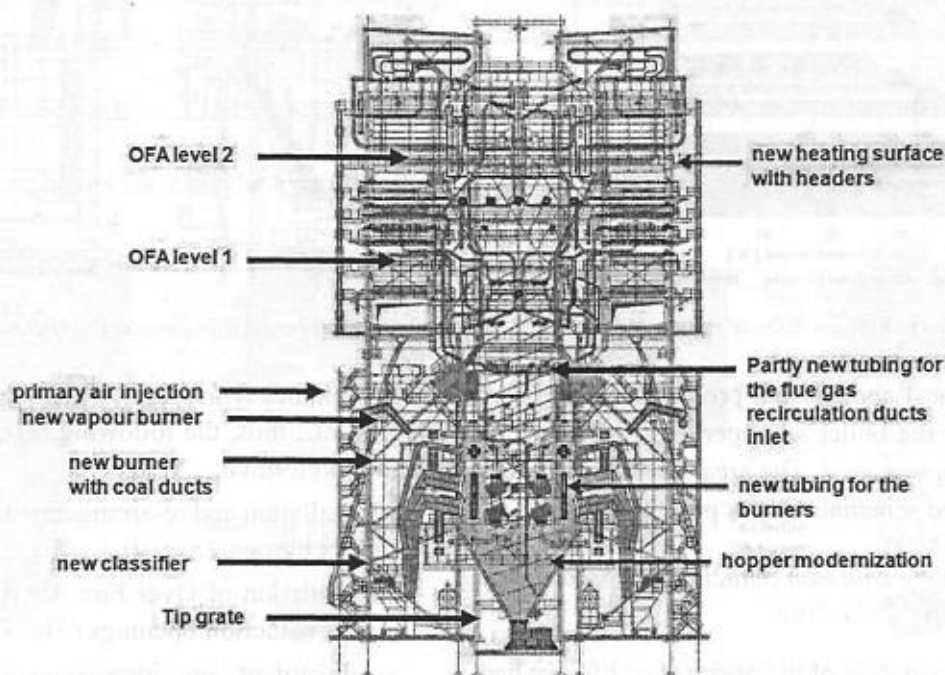


Fig. 2. - Major rehabilitation areas of the existing boilers.

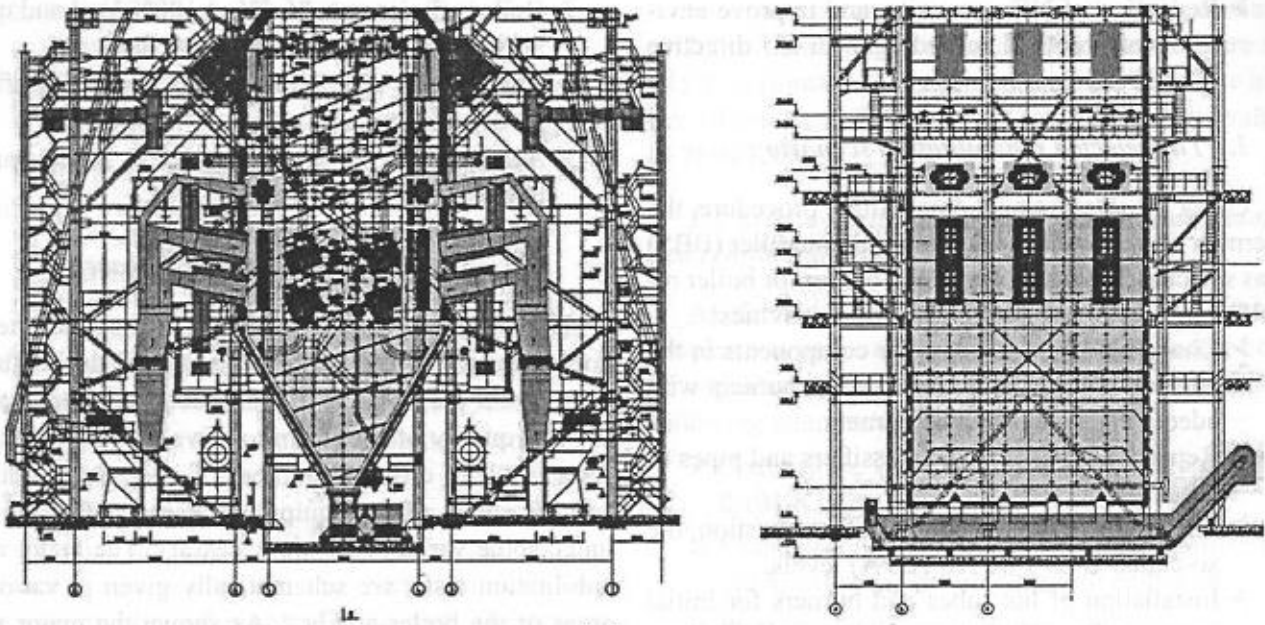


Fig. 3. - New boiler rehabilitation re-arrangements at the bottom part.

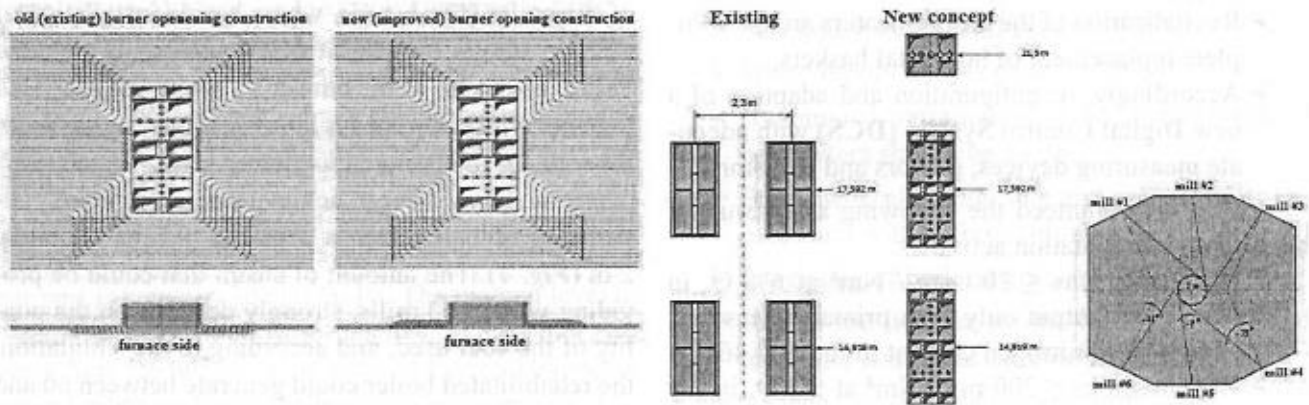


Fig. 4. - Old and new burner's openings and locations with new angles for coal supply into the boiler.

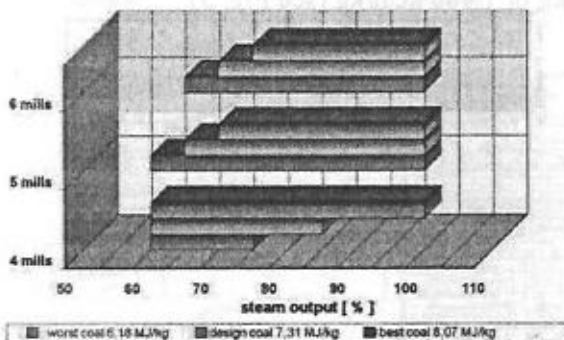


Fig. 5. - Steam output vs. number of mills.

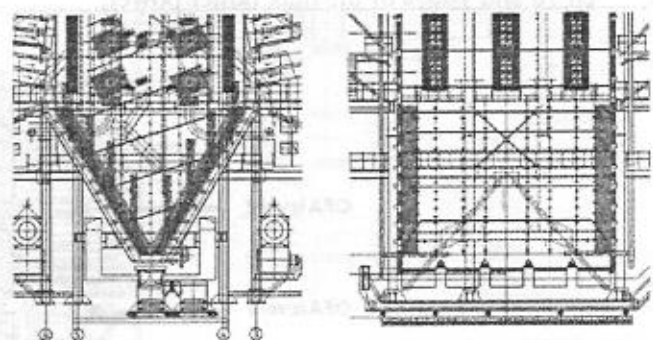


Fig. 6. - Erosion protection area using thermal coating.

For better heat and erosion protection of the heat surfaces inside the boiler's hopper area, a process of thermal coating was used. The area where this protection was applied schematically is presented in Fig. 6.

### 1.7.2 Achieving emission reductions in accordance with EU Directive 2001/80/EC

Beside prolongation of the operational life, we had to take into account that this prolongation must be in

full compliance with this environmental EU Directive 2001/80/EC, thus, the following actions were envisaged and performed:

- Installation and re-arrangement of the new Low-NO<sub>x</sub> burners (Fig. 4),
- Installation of Over Fire Air (OFA) in 2 levels after resuction openings (Fig. 7),
- Adjustment and improvements of coal mills (Fig. 8),

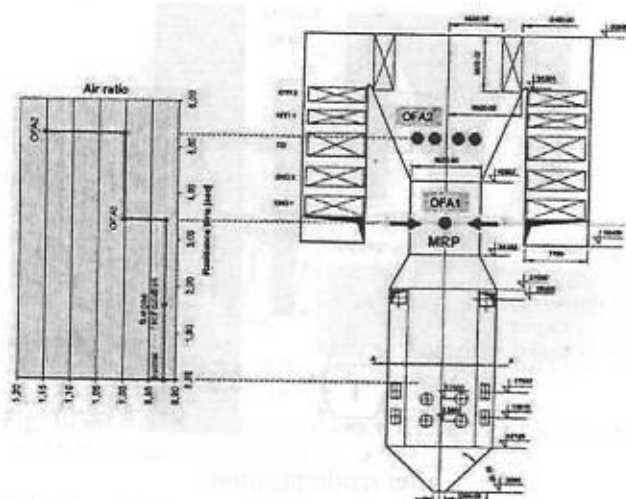


Fig. 7. - Location of two Over Fire Air (OFA1 & OFA2) at two levels inside the boiler

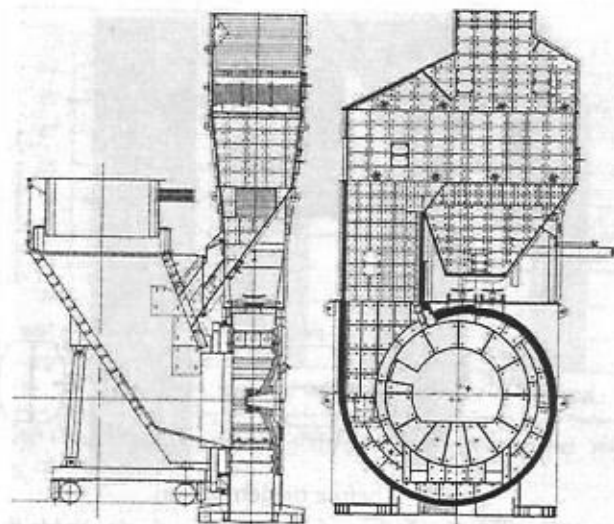


Fig. 8. - New mills with mill fans

- Increase of controlled air by sealing measures,
  - at refractory and insulation,
  - at openings in coal conveyors,
  - at sealing of cold air damper in resuction duct, and
  - at tip grate.
- Optimization of coal/air ratio, including
  - extended air flow measurements, and
  - extended coal flow weighing.
- Optimizing of primary air injection into recirculation duct.

Investigation of the proposed measures and validation of the expected results after performing the full boiler modernization, was done using a special 3D model of the existing boiler before and after the proposed modernization (see Fig. 9). Using these models, the extended 3D CFD analysis of the whole combustion system was done at the University of Stuttgart. The obtained simulation results before and after modernization of the boiler for the flue gas valocity and temperature are presented in the Figs. 10 and 11. New and improved techniques for coal duct arrangements

shown in Fig. 12 and for hot air duct distribution system shown in Fig. 13 were also considered. Finally, the improvements in the upper boiler parts were also done by means of installation of two Over Fire Air (OFA1 and OFA2) systems approximately at boiler's levels 41m and 52m which provide smooth and stable flue gasses in the boiler's upper part and evenly distributed temperature field as can be seen from Fig. 14.

### 1.1.1 Improvement of boiler's efficiency

Taking into consideration that the original boilers were constructed in the yearly 1980s, from one side, and the recent improvements in the technology and materials, the existing boiler efficiency was not high. However, during the process of modernization and with utilization of modern materials as well as modern simulation technology such as 3D CFD analysis in the design stage, we could expect increase of the boiler efficiency as one of the important rehabilitation outcomes. The bidder did intensive research how to improve the boiler's efficiency and with the provided data for the coal quality, BBS offered that even in the worst

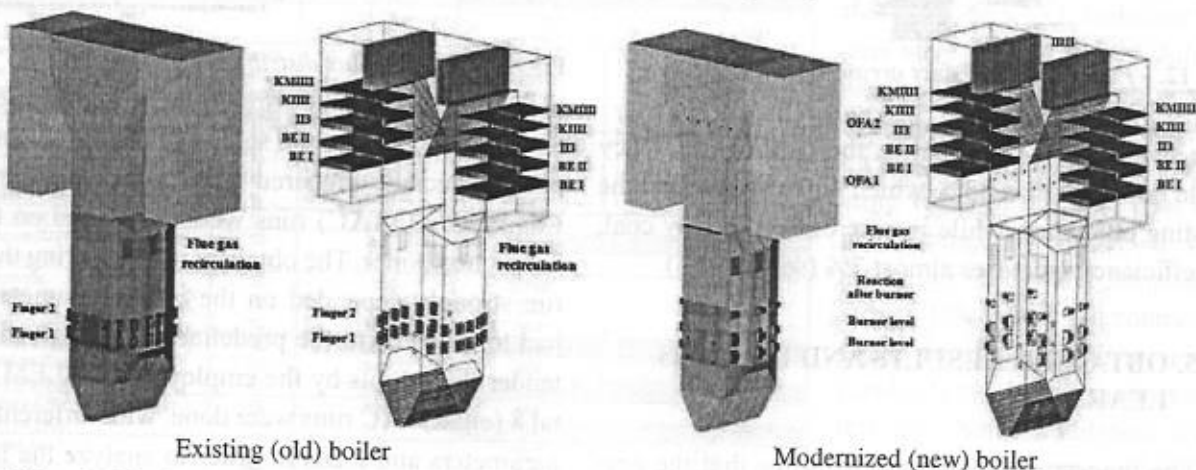


Fig. 9. - 3D model for CFD analysis.



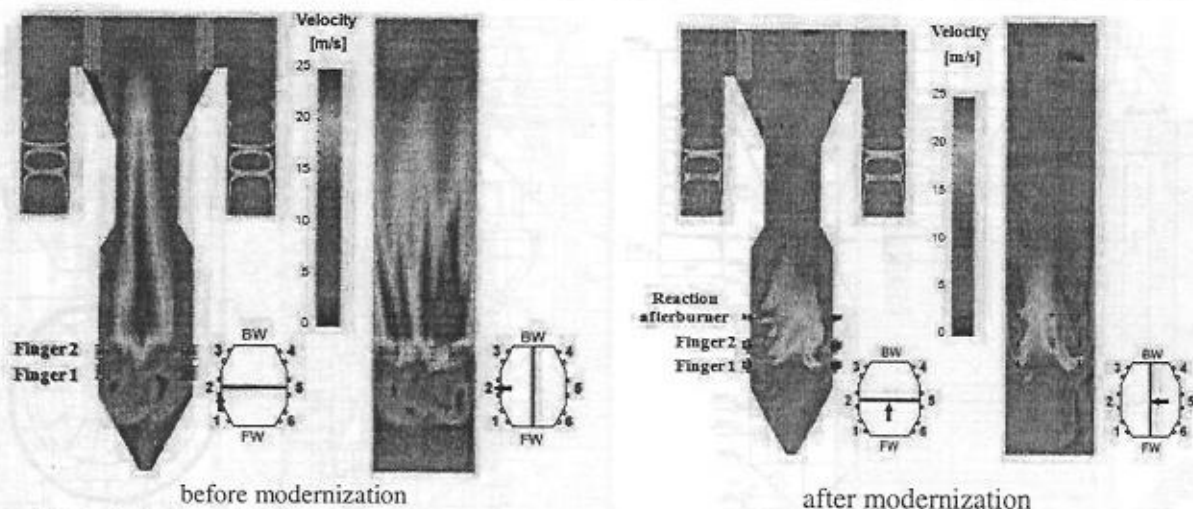


Fig. 10. - CFD simulation of the flue gas velocity inside the boiler.

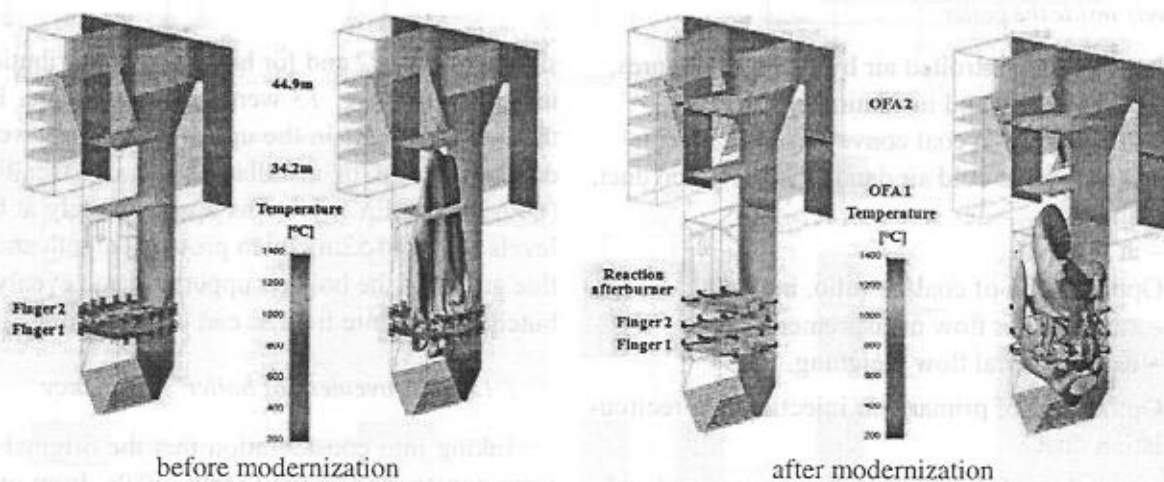


Fig. 11. - CFD simulation of the temperature inside the boiler.

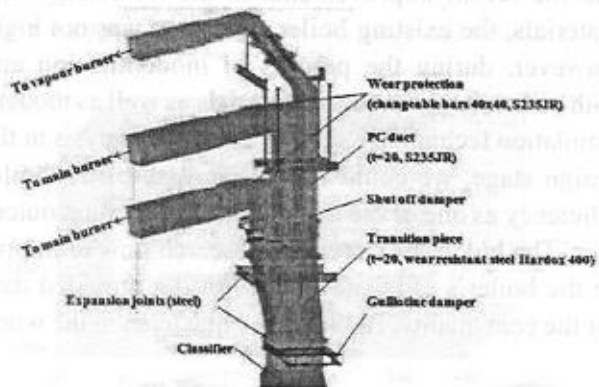


Fig. 12. - Pulverized coal duct arrangement.

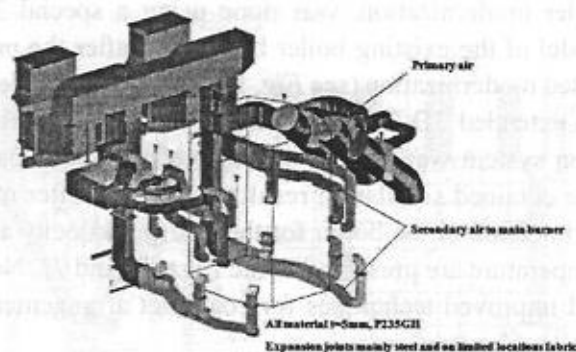


Fig. 13. - Hot air duct distribution system.

case scenario for coal quality, the boiler's efficiency could be higher than 85%, which is 4% higher than the existing efficiency, while in case of best quality coal, the efficiency increases almost 7% (see Fig. 15).

### 5. OBTAINED RESULTS AND LESSONS LEARNED

The biggest challenge was to prove that the executed rehabilitation activities result with the expected

outcomes and that they are the same and/or even better as guaranteed by the selected bidder. For that purpose a specially prepared tests, so-called "Test after Completion" (TAC) runs were performed on the rehabilitated boiler. The obtained results during the TAC run strongly depended on the initial parameters that had to be equal to the predefined values given in the tender documents by the employer, i.e. ELEM. In total 8 (eight) TAC runs were done, with different initial parameters and loads in order to analyze the boiler's response under various operational conditions. The

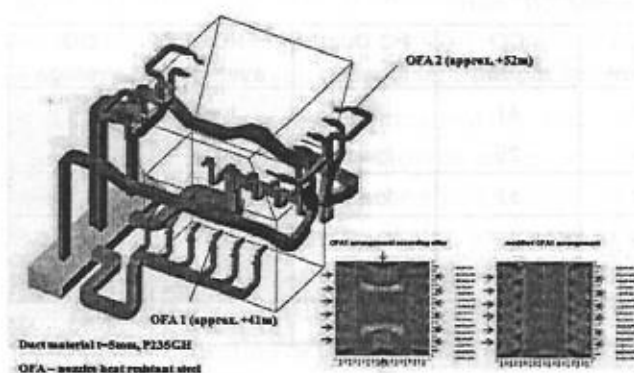


Fig. 14. - Over Fire Air OFA1 and OFA2 systems with achieved temperature distributions.

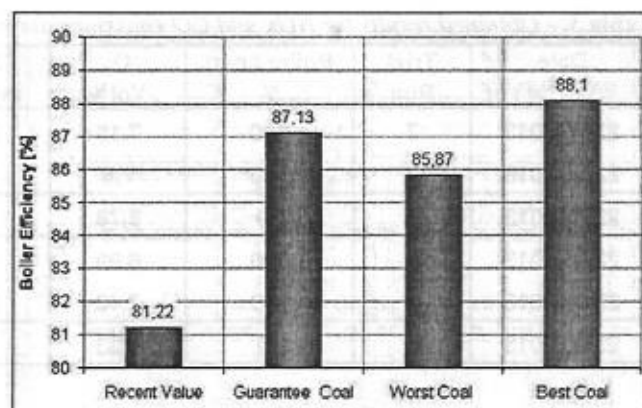


Fig. 15. - Expected boiler's efficiency in comparison with the coal quality

Table 1. - Data obtained during the TAC runs.

Trial Run		1	2	7	8	3	4	5
Date		21.05.13	21.05.13	22.05.13	22.05.13	23.05.13	23.05.13	24.05.13
Number of Mills in Operation	-	6	5	5	5	6	5	5
Unit Load	%	100	60	100	60	100	70	80
Generator Output	MW	230	146	224	143	225	169	185
HP Mass Flow	t/h	706,0	424,2	703,3	428,0	691,3	526,3	577,7
Pressure Feedwater	kg/cm <sup>2</sup>	184,6	154,9	186,5	155,7	181,0	162,5	170,5
Pressure Life Steam	kg/cm <sup>2</sup>	134,4	132,7	134,3	132,4	133,6	132,8	132,9
Presser Cold Reheater Line	kg/cm <sup>2</sup>	31,0	19,3	30,7	19,4	30,4	23,5	25,5
Temperature Feedwater	°C	236,6	213,0	236,2	213,4	235,6	223,3	227,2
Temperature HP Steam	°C	537,6	540,5	539,4	539,8	539,2	540,5	539,2
Temperature Cold Reheater Line	°C	329,5	298,3	329,0	315,5	328,5	309,1	315,0
Temperature Reheated Steam	°C	539,4	541,1	539,2	538,9	539,5	540,2	537,6
Temperature Air at RAPH Inlet	°C	63,8	68,9	62,2	75,1	62,1	71,9	67,2
Temperature Flue Gas Boiler / RAPH Outlet	°C	195,6	193,8	194,4	193,7	194,3	190,7	190,5
Concentration Oxygen ECO (wet)	Vol%	2,07	2,73	2,07	2,63	2,03	2,34	2,29
Concentration Oxygen RAPH Outlet(dry) <sup>1)</sup>	Vol%	3,29	4,24	3,29	4,09	3,23	3,68	3,61

Table 2. - Comparison of the obtained and simulated results with the guaranteed.

Column number		#1	#2	#3
Case		Original design	TAC run 7	Guarantee conditions
Comment		for info only	Recalculation of measurement data	Simulation with guarantee parameters
HP Mass flow	t/h	700	703	700
IP Mass flow (inlet)	t/h	602	602	602
Fuel mass flow	t/h	302,0	280,3	302,5
Generated Heat	MW	540,3	552,8	539,4
Combustion power	MW	606,1	620,8	612,7
HP pressure (outlet)	MPa	14,00	13,40	14,00
ZD-Druck KZUE	MPa	2,80	3,10	2,80
Lower Heating Value	MJ/kg	7,310	7,995	7,310
Air excess furnace outlet	-	1,15	1,16	1,15
Air excess boiler outlet (RAPH)	-	1,22	1,19	1,18
Combustion air flow	Nm <sup>3</sup> /h	785.300	776.300	793.900
Hot air flow RAPH outlet	Nm <sup>3</sup> /h	643.900	481.310	492.220
Flue gas flow RAPH inlet	Nm <sup>3</sup> /h	1.028.900	1.020.400	1.040.100
Flue gas flow RAPH outlet	Nm <sup>3</sup> /h	1.091.500	1.046.800	1.067.200
Heat loss due to heat in slag	%	0,24	0,11	0,26
Heat loss due to heat flue gas	%	11,04	11,11	11,95
Heat loss due to radiation	%	0,43	0,41	0,41
Heat loss due to combustibles in refuse	%	1,70	0,77	0,77
Percentage of hot air	%	62,0	62,0	62,0
Air temperature RAPH inlet	°C	60	62	60
Air temperature RAPH outlet	°C	302	287	297
FG temp. furnace	°C	1.155	1.188	1.155
FG temp. ECO	°C	318	320	332
FG temp. RAPH outlet	°C	180	194	200
HP Temperature BFW	°C	252	236	252
HP Temperature Eco outlet	°C	342	327	337
HP Temperature SCP	°C	545	539	545
IP Temperature CRL	°C	330	330	330
IP Temperature SKS	°C	545	539	545
HP spraywater flow	t/h	70,0	70,3	70,0
IP spraywater flow	t/h	0,0	0,0	0,0
Boiler efficiency	%	86,59	87,60	86,61

main data for each of these TAC runs is given in Table 1.

The main conclusions derived from all runs showed that the most important rehabilitation targets, such as the boiler efficiency, the steam production target and the NO<sub>x</sub> and CO emission targets were fully achieved. Additionally, the boiler operation with 5 mills at nominal load and 700 t/h was achievable in case the heating value of the used coal was in the range of contracted data, the boiler feed water temperature was 15K below the contracted value, resulting in the increased combustion power by approximately 2%. Some additional benefits, not initially expected during design phase, were also observed

Table 3. - Obtained results for NOx and CO emissions during several TAC runs.

Date	Trial Run	Boiler Load %	O <sub>2</sub> Vol%	NO <sub>x</sub> mg/Nm <sup>3</sup>	CO mg/Nm <sup>3</sup>	FG Duct location	NOx average	CO average
22.05.2013	7	100	7,16	200	41	top	197	33
22.05.2013	7	100	7,6	194	25	lower		
22.05.2013	8	60	8,78	157	17	lower	157	17
23.05.2013	3	100	6,99	189	25	top	196	21
23.05.2013	3	100	7,43	203	17	lower		
23.05.2013	4	70	8,33	186	13	lower	186	13

among them, the mass flow of boiler bottom ash after modernization was approximately 10% lower as predicted; the content of unburned char in dry ash (ESP) was also lower than expected; the boiler operated very well and reliable; the installed firing system fulfilled the requirements concerning low NOx-combustion, and the CO-emission was very low.

As can be seen from Table 1, the TAC runs also exhibits some minor deviations from the guaranteed data needed for boiler testing (see TAC Run #7), mostly due to different fuel used (lower ash, higher heating value, and higher water content than in design coal), different feed water temperature (236°C instead of 252°C as predefined), different HP steam temperature during TAC runs (539°C instead of 545°C as predefined), and different HP steam mass flow (703 t/h instead of 700 t/h as predefined). However, as can be seen this minor changes in the input data, does not have significant influence on the obtained TAC results.

To compare the TAC results with original design data provide in the tender offer, special boiler simulation software named "BODI" was used. The calculated data obtained with this software, compared with the TAC run #7 data and the original design data offered at tendering process, are compared and presented in Table 2. It is obvious that the TAC run proves that the boiler rehabilitation tasks were performed correctly resulting in the desired modernized boiler with

the efficiency larger than 86.5% as offered by the economic operator.

With respect to the environmental achievements gained with the boiler rehabilitation, the obtained results for NOx and CO emissions are fully compliant with the expected (NOx < 200 mg/Nm<sup>3</sup> (@6% O<sub>2</sub>, dry, using only primary measures, and CO < 50 mg/Nm<sup>3</sup> (@6% O<sub>2</sub>, dry), as shown in Table 3, and Fig. 1.

### 5. CONCLUSIONS

In this paper, the extensive boiler rehabilitation program for TPP Bitola is described. Starting from major preparation works, tendering and selected the best offer, rehabilitation process and the obtained results and lessons learned are presented. This extensive rehabilitation process was mostly initiated due to large number of operation hours that all three units of TPP Bitola already had, thus the future operation of this power plant which has the major role in electricity production in the Republic of Macedonia was put under question. Thus, the major expected outcome was performing major rehabilitation of all three boilers that could provide extension of the operational life of the power plant at least for additional 120.000 hours, or approximately 15-16 years more. In parallel, the increase of the boiler efficiency, standard operation with reduced quality of the local coal with (n-1) mills and

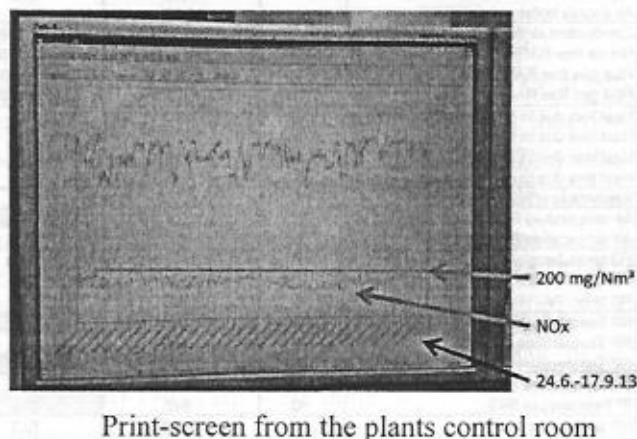
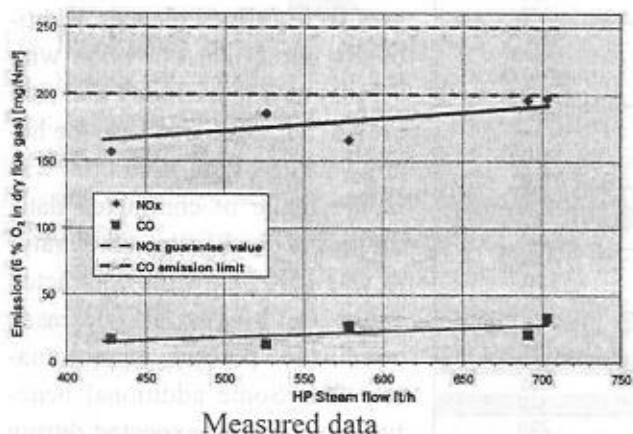


Fig. 16. - Measured data for NOx and CO emissions and on-screen real-time data.



especially fulfillment of the more strict environmental standards defined with the EU Directive 2001/80/EC, were also part of the requirement set by the employer.

The rehabilitation results obtained by the TAC (Test after Completion) runs showed and proved the selected approach and confirm the guaranteed parameters set as requirements in the tender documents. The major lesson learned during execution of the whole project was that the quality of the preparation works taken before execution of the rehabilitation program is of crucial importance.

## REFERENCES

- [1] ELEM, "Investment plan 2009-2016", February 2009.
- [2] European Commission, "Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants", European Commission Report, July 2006.
- [3] ELEM, "Feasibility study for Modernization of TPP Bitola", 2008.
- [4] И. Мицкоски, Д. Коруноски, Х. Мицкоски, "Подготовка на тендерска документација за втора фаза на објавениот тендер за модернизација на агрегатите во РЕК Битола и евалуирање на пристигнатите понуди," ЕЛЕМ, 2008 Скопје,
- [5] И. Мицкоски, Х. Мицкоски, "Одредување на ресурс на пароводи, колектори и грејни површини на Блок 1 во ТЕ-РЕК Битола после одработени 200000 часа," ЕЛЕМ, 2010, Битола.
- [6] И. Мицкоски, Х. Мицкоски, "Одредување на ресурс на пароводи, колектори и грејни површини на Блок 2 и Блок 3 во ТЕ-РЕК Битола после одработени 200000 часа," ЕЛЕМ, 2011, Битола.
- [7] "DIRECTIVE 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants, (The LCP Directive)," Official Journal of the European Communities, 2001.
- [8] PHARE, "Action plan for lignite supply to TPP in Bitola," PHARE Project, December 2002.
- [9] MWH, "Bitola TPP, Technical Audit and Project Review for Rehabilitation and Performance Improvement," EBRD Project Document ID: 455 01364, June 2009.