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Comparative analysis of firing different coal blends for boiler 12 at TPP "Maritsa East 2"

Totyo Totev[a*], Dinko Kanev[b]

[a]*Technical University of Sofia, 8 Kl. Ohridsky Blvd., 1000 Sofia, Bulgaria*

[b]*Technical University of Sofia, 8 Kl. Ohridsky Blvd., 1000 Sofia, Bulgaria*

[a]*Email: t-totev@tu-sofia.bg*

[b]*Email: morbit@abv.bg*

Abstract

Firing Bulgarian lignite coals for generating electric energy is related to a number of problems connected to the high ash and moisture content which determines its low calorific value. Moreover the high content of combustible sulfur leads to considerable expenses for the desulphurization systems. An alternative for improvement of the technical, economical and environmental indicators for the operation of the boilers at TPP "Maritsa East 2" is the combustion of coal blends that include fuels from different coal basins. This paper describes the planning and the conduction of such an industrial experiment. Results from the operation of the boiler when firing only coals from the "Maritsa East" basin have been presented to serve as a basis for comparison with theresults obtained during combustion of coal mixtures.

Keywords: lignite coal characteristics; firing coal blends; feasibility study; assessment of pollutant emissions.

1. Introduction

A large part (about 35%) of the generated electrical power in the Republic of Bulgaria is a result from firing local lignite coals. The coal basin "Maritsa East" is situated on 240 km^2 and produces 25 million tons of coals per year. The characteristics of these coals are highly variable [12]. They have a low calorific value and very high content of combustible sulfur. An analysis for a wide range of quality variations of these coals is shown on Table 1.

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* Corresponding author.

E-mail address: t-totev@tu-sofia.bg.

Table 1. Characteristics for a wide range of quality variation of the coal fired at “Maritsa East”

A^d, %	A^r, %	W^r, %	C^r, %	H^r, %	O^r, %	S^r, %	N^r, %	Q_i^r, kJ/kg	V^{daf}, %
25,00	10,94	56,26	22,07	1,84	6,78	1,72	0,39	7108,30	55-65
30,00	13,67	54,45	21,28	1,78	6,54	1,94	0,37	6794,85	55-65
35,00	16,57	52,65	20,35	1,70	6,26	2,11	0,36	6425,11	55-65
40,00	19,66	50,84	19,29	1,61	5,93	2,33	0,34	5999,07	55-65
45,00	22,93	49,04	18,10	1,51	5,56	2,54	0,32	5516,73	55-65

Eight of those boilers firing lignite coals type P-62 are manufactured in Russia at the JSC Machine-Building Factory of Podolsk. Each one of them is designed to generate 670 t/h live steam with the following parameters: pressure 12,75 MPa and temperature 545 ^oC. They are T-shaped and the generated flue-gas is distributed into two flows – Figure 1.

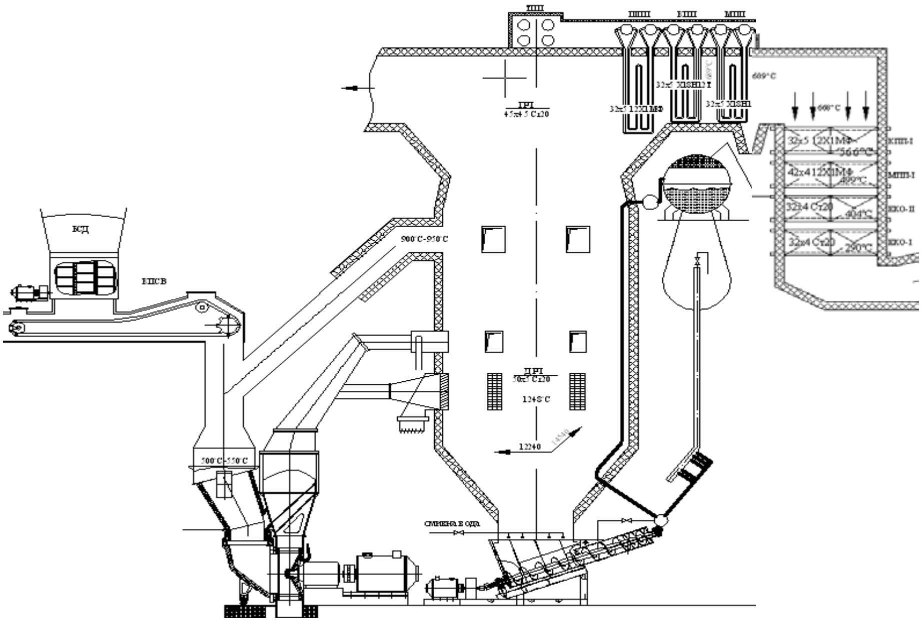

Fig.1. Arrangement of the boiler

The preparation for the combustion of the coals is performed in the coal preparation systems (CPS) with direct injection [14]. At the milling stage a part of the flue-gas that circulates from the top of the furnace into the mills which allows the fuel to be further dried. Boilers type P-62 are equipped with 8 individual CPS with direct injection and dust concentrators. The CPS are designed for dosing, transporting, drying, milling and feeding the pulverized coal to the boiler. The recirculation ducts are used for suction of flue-gas and pre-drying the fuel. Each CPS consists of the following equipment shown in Figure 2:

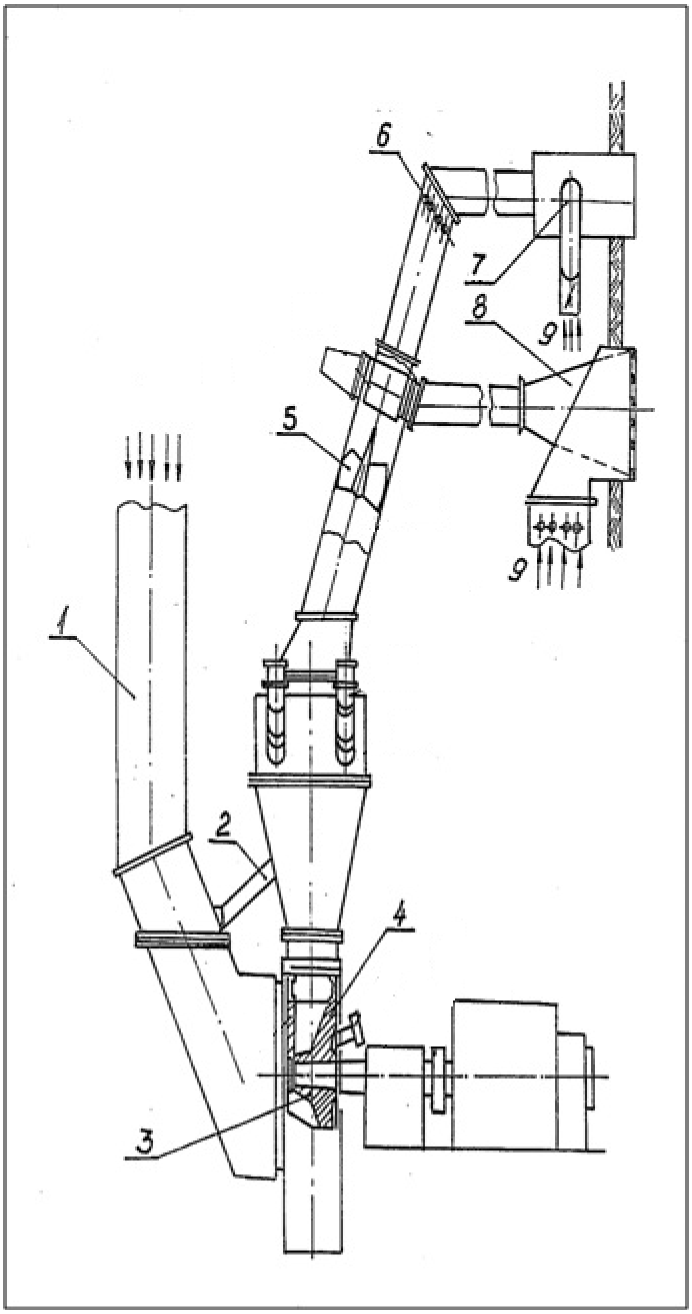

Fig. 2. Equipment of the coal preparation systems

- Gas ducts (GD)	pos. 1
- Valve of raw coal duct	pos. 2
- Mill fan (MF)	pos. 3
- Cut valve over the mill door	pos. 4
- Dust concentrator (DC)	pos. 5
- Isolation valves of dust ducts	pos. 6
- Vapor burner (VB)	pos. 7
- Main burner (MB)	pos. 8
- Combustion air	pos. 9

Pre-crushed coal /particle sizes up to 40 mm/ is filed and stored in the raw coal bunkers /RCB/ [9]. The dispensers capture coal from the bunkers and pass them into the feeders. The revolutions of the dispensers and the feeders are synchronized, which provides a uniform, continuous and adjustable supply of coal to the raw coal duct and to the gas ducts. Dispensers and feeders working synchronously are called combined raw coal feeder (CRCF). In recirculation ducts, under the influence of high temperature, drying gas evaporates some of the moisture of the coal. Most of the moisture evaporates in the mill simultaneously with grinding. The coal dust enters the separator where its separation is executed. The largest particles pass through the feeder for recirculation and return in the mill for additional grinding. The coal dust that has been more finely grinded enters the dust concentrator, the dust ducts and the burner. The dust-gas mixture at the outlet of the mill consists of drying gases, water vapor, unorganized air and coal dust. The dust concentrator divides the coal dust along height of the burners under the action of the centrifugal force in the following way: dust-gas mixture with more coal dust goes in the lower two floors and a large amount of gases and water vapor and a small amounts of coal dust goes to the third (vapor burner) floor. Hot air is fed on each floor of the burner, which together with the infiltrations in the coal preparation system provides the air needed for combustion. The hot air is also called secondary and the unorganized infiltration is defined as primary air. The burners are directed at a certain angle to the center of the furnace, resulting in tangential flame being formed, which provides mixing and combustionof the fuel – Figure 3.

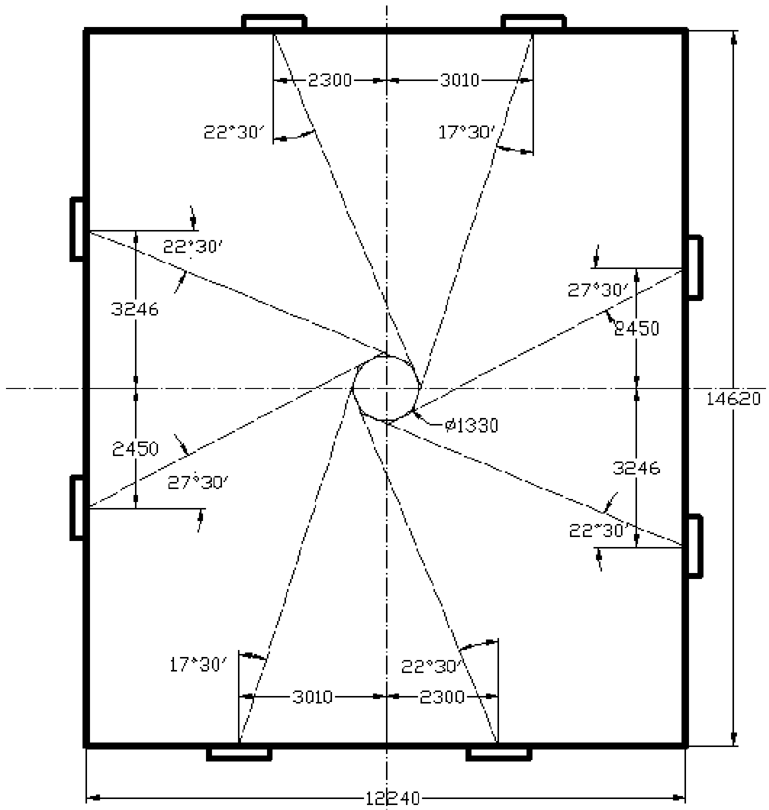

Fig. 3. Tangential flame

Increasing the efficiency of the boilers firing lignite coals often results in worse ecological indicators. Therefore the assessment of the thermal efficiency should be executed in regard of the resulted pollutants. In this aspect an assessment of the SO_2 (respectively the operation of the FGD), NO_x emissions and flue-dust concentration is in order [2,3,5,6,10,13]. It is also mandatory for the unit power consumption to be taken into consideration. One of the possibilities for changing the operation of the boilers at TPP "Maritsa East 2" is the implementation of firing coal blends from "Maritsa East" basin and another basins [1,4,7,8]. At TPP "Maritsa East 2" are firing coals with high moisture content (from 50% on A^d=45% to 59% on A^d=28%), high content of combustible sulfur (from 2,5% to 5% on dry basis) and calorific value from 5 500÷7 100 kJ/kg. The high sulfur content results in higher SO_2 concentration in the flue-gas which leads to a higher limestone slurry consumption from the FGD. This determines the need for an investigation of the possibility for firing coal mixtures. A suitable option is the coals from "Bela

Voda" mine – located near the town of Pernik. These are brown coals with high ash content (A^d=35÷50%) with lower moisture content (W^r=15÷25%) and sulfur less than 1% [11].

2. Materials and methods

2.1. Methods

The objectives of the industrial scale investigation are:
1. An assessment of the possibility for firing such coal blends in regard to the safety of the operation of the boiler – stability of the combustion process; distribution of the thermal load to the heating surfaces etc;
2. An assessment of the feasibility and the ecological indicators for the operation of the boiler when firing coal mixtures and comparing the results with normal operational conditions;
3. Determination of the optimal ratio of the fuel blends.

2.2. Materials

The investigation was realized for Boiler 12 (type P-62) and its respective FGD 8. For the purposes of the tests a separate coal figure was created. The characteristics of the coals are monitored in a manner that ensured an average characteristic of the coals. 10 000 t of coals from "Bela Voda" mine were delivered for the tests. The average characteristics of the fired coals are summarized in Table 2.

Table 2. Average characteristics of the fired coals

Proximate analysis	**Sign**	**Dimension**	**"Maritsa East" basin**	**"Pernik" basin**
Ash	A^d	**%**	33,00	47,50
Moisture	W^r	**%**	53,90	21,30
Net calorific value	Q_i^r	**kJ/kg**	6600	9760
Ultimate analysis				
Carbon	C^r	**%**	20,19	26,35
Hydrogen	H^r	**%**	1,70	1,90
Sulfur	S^r	**%**	2,09	0,98
Nitrogen	N^r	**%**	0,35	0,82
Oxygen	O^r	**%**	6,12	4,86
Volatiles	V^{daf}	**%**	55-60	52,20
Temperature of ash melting – deformation	t_A	^oC	1050,00	1141,00
Temperature of ash melting -hemisphere	t_B	^oC	1200,00	1275,00
Temperature of ash melting- fluidity	t_C	^oC	1250,00	1308,00

Carrying out the experiments involved two stages:

Stage A. Firing coals only from "Maritsa East" basin – Test1 and Test 2.

During the tests an assessment of the operation of the following systems was performed:

- Assessment of the operation of 2 CPS – CPS 12B and CPS 12E;
- Heat balance tests of Boiler 12 performed according to [15];
- Environmental evaluation of the pollutants – SO_2, NO_x and CO concentrations in the flue-gas on the outlet of the boiler;
- Assessment of the operation of FGD 8.

Stage B. Firing coal mixtures from "Maritsa East" basin and "Pernik" basin – Test 3, Test 4, Test 5 and Test 6.

During the tests an assessment of the operation of the following systems was performed:

- Assessment of the operation of 2 CPS – CPS 12B and CPS 12E;
- Heat balance tests of Boiler 12 performed according to [15];
- Environmental evaluation of the pollutants – SO_2, NO_x and CO concentrations in the flue-gas on the outlet of the boiler;
- Assessment of the operation of FGD 8.

The ratio of the fired coal mixtures are shown in Table 3.

Table 3. Ratio of the fired fuel mixtures

		A^d %	**W^r %**	**Q_i^r kJ/kg**	**SO_2 mg/Nm^3**	**Ratio Maritsa-East/Pernik basins**
Test 3	AM	38,9	47,9	6 608	14 252,0	0,9 / 0,1
	PM	36,4	45,9	7 521	13 112,0	0,75 / 0,25
Test 4	AM	38,4	46,9	7 006	13 197,0	0,8 / 0,2
	PM	35,1	49,9	7 064	13 994,0	0,85 / 0,15
Test 5	AM	33,1	52,0	6 976	13 115,0	0,8 / 0,2
	PM	36,2	48,0	7 152	13 434,0	0,8 / 0,2
Test 6	AM	33,9	50,6	7 006	14 995,0	0,9 / 0,1
	PM	37,0	48,1	6 943	13 313,0	0,85 / 0,15

During the tests the following parameters were controlled for the:

Fuel:

- Moisture content;
- Ash content;
- Calorific value.

CPS operation:

- Ventilation efficiency;
- Power output of the milling fans;
- Particle size of the pulverized coal;
- Visual assessment of the abrasive wearing of the milling fans (after the tests).

Combustion chamber:

- Temperature measurement in the combustion chamber;

- Unburned fuel in the slag.

Boiler operation:

- Temperature of the flue-gas;
- Temperature of the steam and the water;
- Measurement of the concentration of the gaseous pollutants on the outlet of the boiler;
- Unburned content in the flue-gas;
- Technical and economical parameters of the boiler (feasibility, fuel consumption and unit power consumption).

FGD operation:

- Efficiency of the desulphurization;
- Limestone slurry consumption
- Technical parameters of the operation of the FGD.

For the assessment of the operation of the CPS a standard method based on heat and drying balance is applied. As the coal blends were prepared this method was further developed. Similarly the same approach was applied for the assessment of the operation of the boiler.

3. Results

3.1. Comparative analysis of the operation of the CPS when firing coals only from the "Maritsa East" basin and when firing coal blends from "Maritsa East" and "Pernik" basins

To compare the operation of the CPS during the preparation of the coals in Table 4 are presented some of their essential parameters. Test CSP-1 and CPS-2 are showing the results from firing coals only from the "Maritsa East" basin. All other results are from coal mixtures firing tests. The ratio of the mixtures is as shown in Table 3. On Figure 4 are summarized the particle sizes of the pulverized coal on the outlet of the classifier.

Table 4. Results for the operation of the CPS during the tests

CPS		**12B**	**12B**	**12B**	**12E**	**12E**	**12E**
Test		**CPS-1**	**CPS-3**	**CPS-5**	**CPS-2**	**CPS-4**	**CPS-6**
Recirculation duct temperature	^oC	897	1000	1024	918	960	951
Temperature after mill	^oC	160	165,30	184,65	183,56	183,65	186,13
Ventilation efficiency –measured	m^3/h	220 440	215 250	211 370	229 210	226 970	221 120
Volume of drying agent needed for evaporation of the moisture from 1kg fuel	m^3/kg	1,35	1,09	1,22	1,40	1,20	1,25
Estimated fuel consumption by the heat balance	t/h	56,26	70,45	57,26	56,43	67,41	62,59

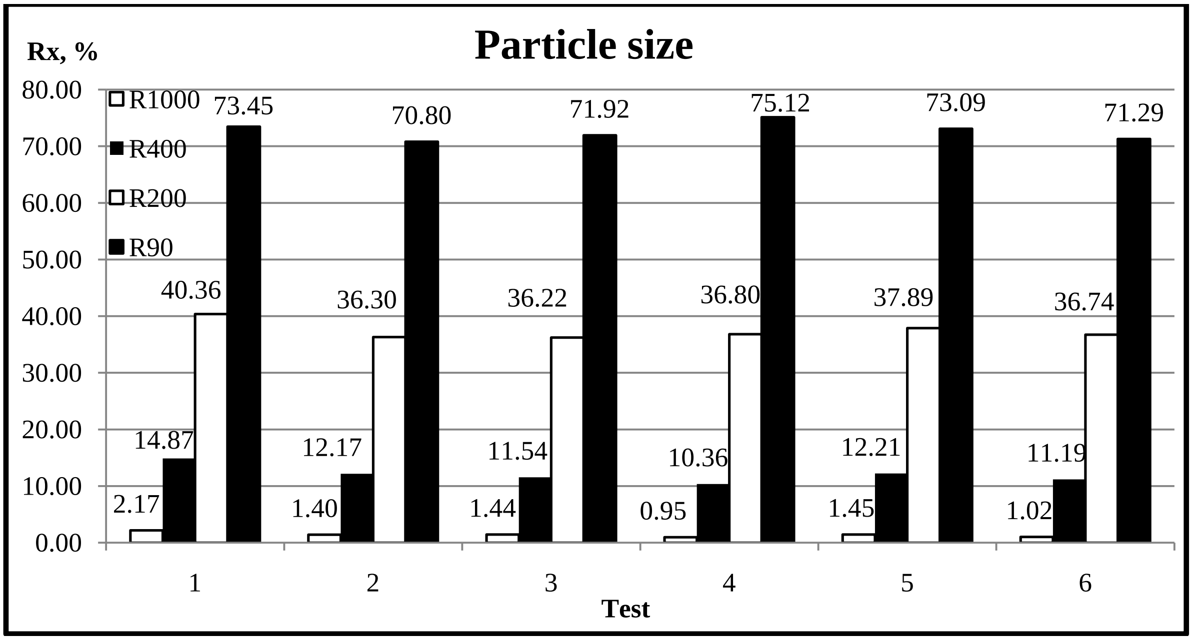

Fig. 4. Pulverized coal particle size on the outlet of the classifier

3.2. Comparative analysis of the operation of Unit 12 when firing coals only from the "Maritsa East" basin and when firing coal blends from "Maritsa East" and "Pernik" basins

As a key indicator of the boiler during the two operational conditions (firing coals only from "Maritsa East" basin and firing mixtures from "Maritsa East" and "Pernik" basins) the feasibility can be used. The obtained values for the feasibility of Unit 12 during the tests are given in Figure 5.

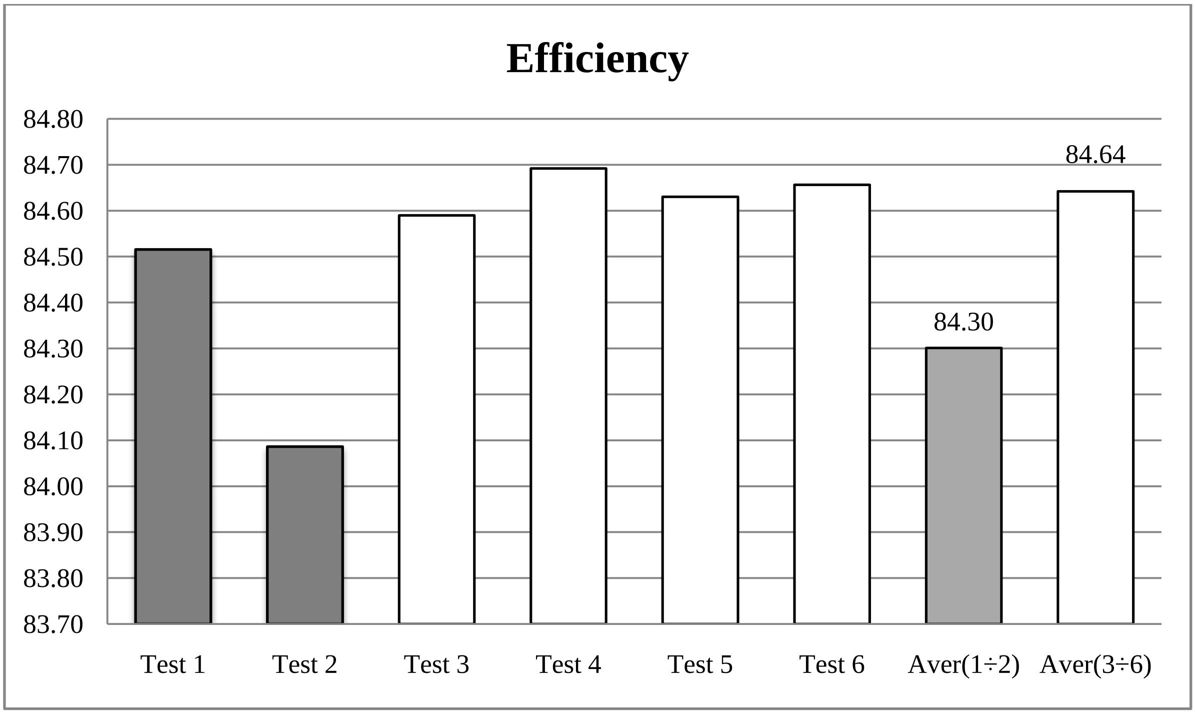

Fig. 5. Efficiency during the heat balance tests

Another essential indicator for the operation of the boiler is the temperature in the combustion chamber. The temperature changes by levels during the heat balance tests, measured with a pyrometer, are presented on Figure 6.

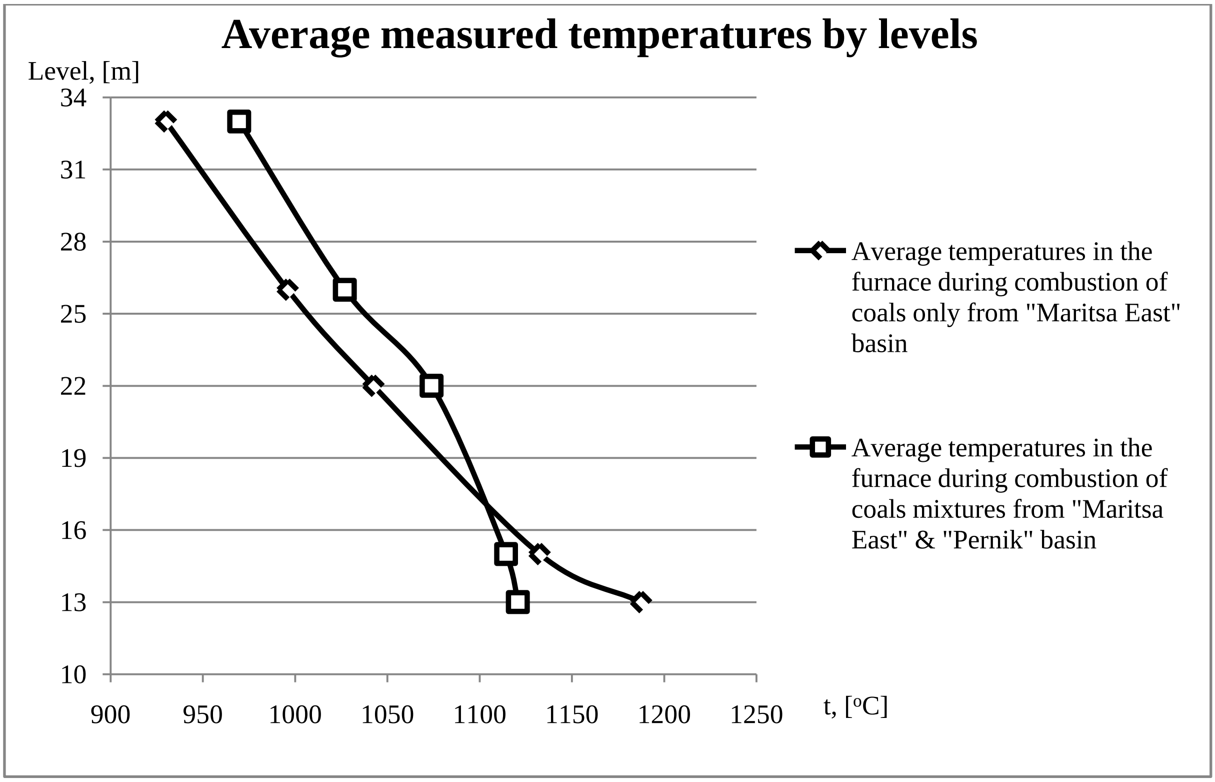

Fig.6. Furnace temperatures when firing coals only from "Maritsa East" and when firing coal mixtures

3.3. Comparative analysis of the emissions of the pollutants from Unit 12 when firing coals only from the "Maritsa East" basin and when firing coal blends from "Maritsa East" and "Pernik" basins

An assessment of the changes in the concentrations of the emissions for the two operational conditions is given on Figure 7 and 8 for SO_2 and on Figure 9 for NO_x.

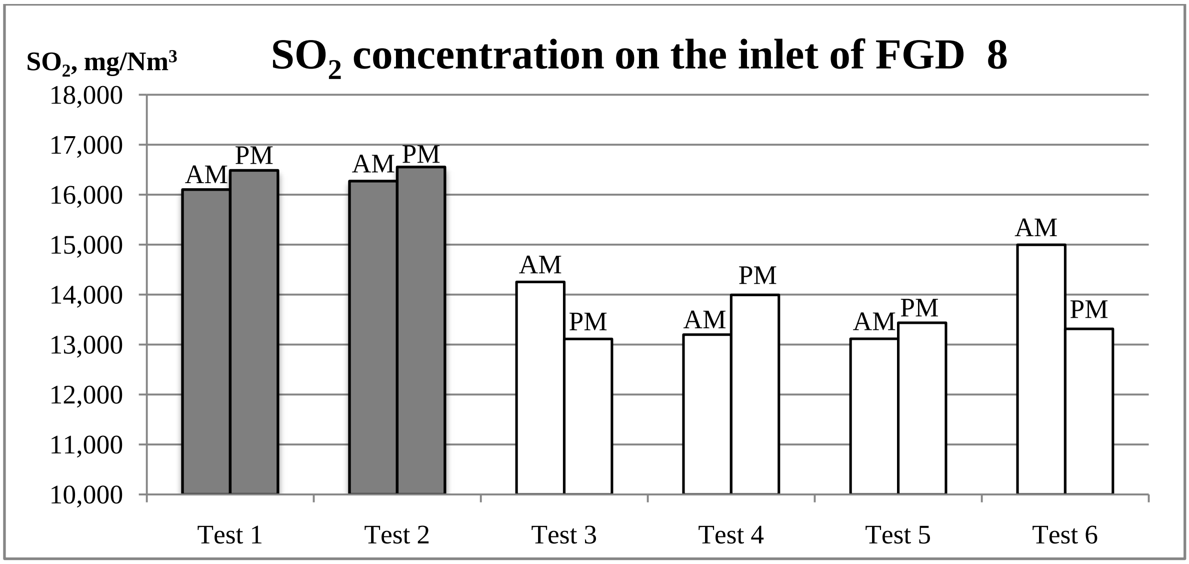

Fig. 7. SO_2 concentration on the inlet of FGD 8 during all tests

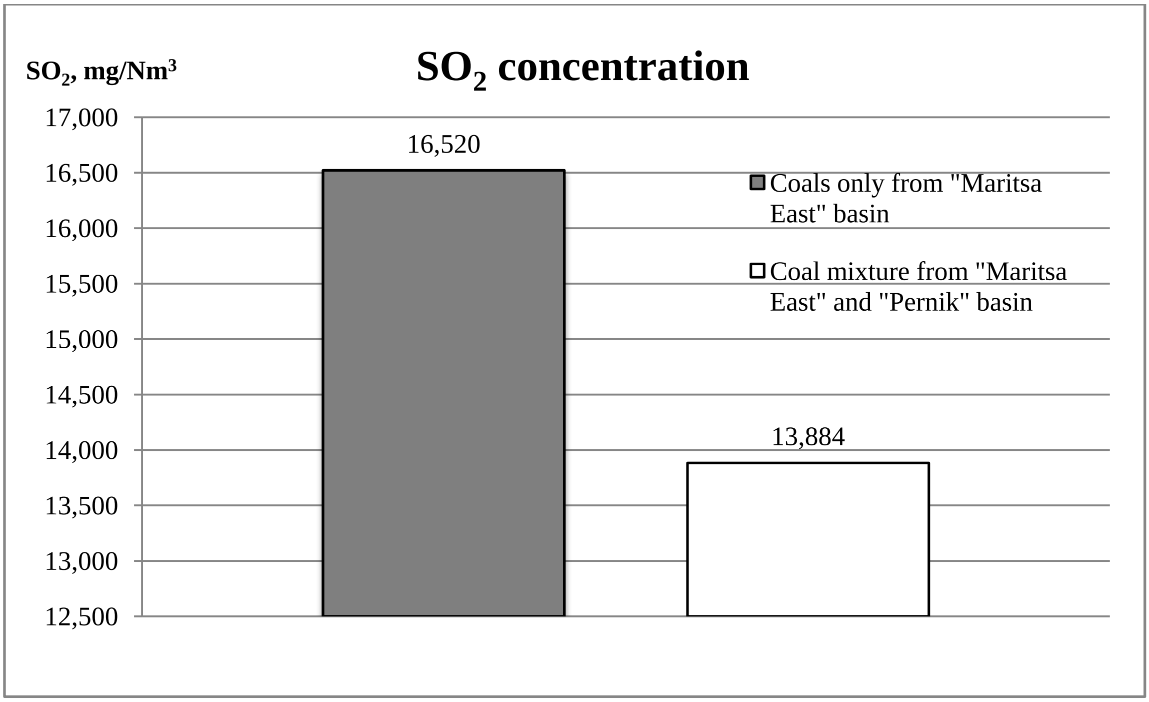

Fig. 8. SO_2 concentration on the inlet of FGD 8 during the heat balance tests in regard of the coal

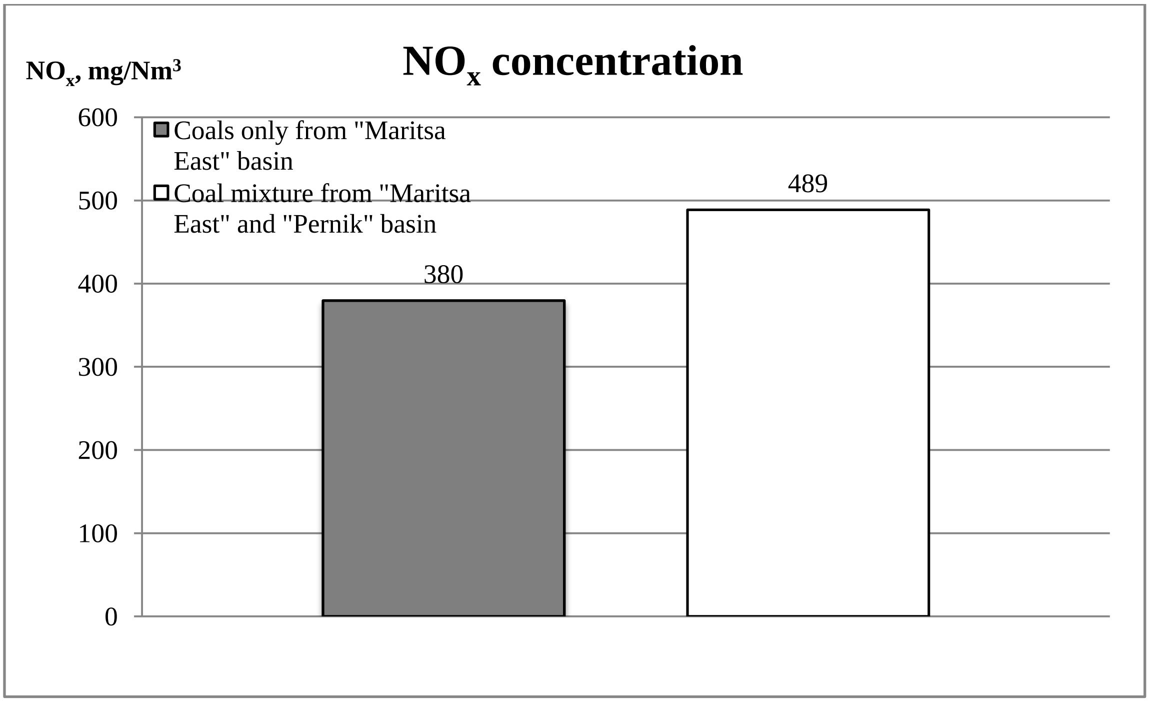

Fig. 9. NO_x concentration on the inlet of FGD 8 during the heat balance tests in regard of the coal

3.4. Comparative analysis of the operation of FGD 8 when firing coals only from the “Maritsa East” basin and when firing coal blends from “Maritsa East” and “Pernik” basins

The key indicators for the operation of FGD 8 are presented in Table 5.

Table 5. Limestone slurry flow and efficiency of FGD Unit 8 when firing coal mixture

		Acidity	**Limestone slurry flow**	**Efficiency**
		pH	**m^3/h**	**%**
Test 1	AM	4,84	98,63	93,33
	PM	4,90	106,80	92,94
Test 2	AM	4,59	99,10	92,41
	PM	4,68	105,00	92,50
Test 3	AM	4,05	81,40	93,10
	PM	3,73	69,71	93,53
Test 4	AM	4,09	72,44	93,48
	PM	4,09	71,43	93,20
Test 5	AM	4,20	73,58	93,95
	PM	3,91	73,71	93,01
Test 6	AM	4,40	79,00	93,86
	PM	4,50	70,00	95,26

3.5. Comparative analysis of the power consumption of Unit 12 when firing coals only from the “Maritsa East” basin and when firing coal blends from “Maritsa East” and “Pernik” basins

During the heat balance tests the power consumption of the Unit is taken into consideration. The average power consumption of the unit for coal milling referred to the type of fuel (coal mixture or not) is shown on Figure 10. It is evident that during one test that takes around 1 hour the consumption for milling is reduced by around 0,5 MW. The explanation of this fact is connected to the operational conditions of the CPS and the lower moisture content of the coal mixture which implies easier milling. Also significant is the higher calorific value. The total power consumption decrease with 1 MW for 1 hour test – Figure 11.

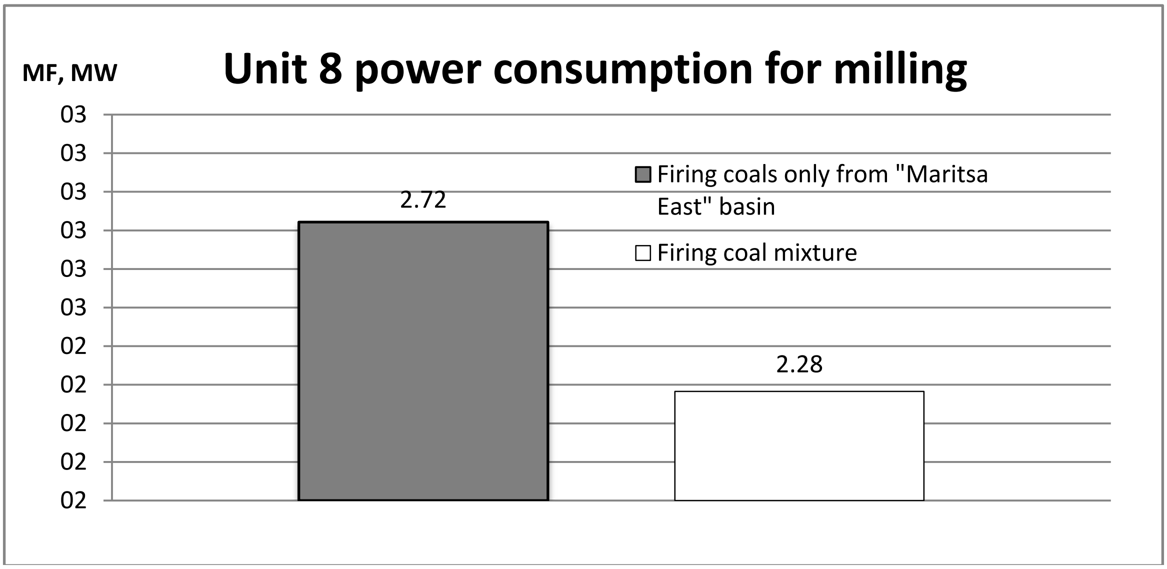

Fig. 10. Power consumption for milling depending on the coal

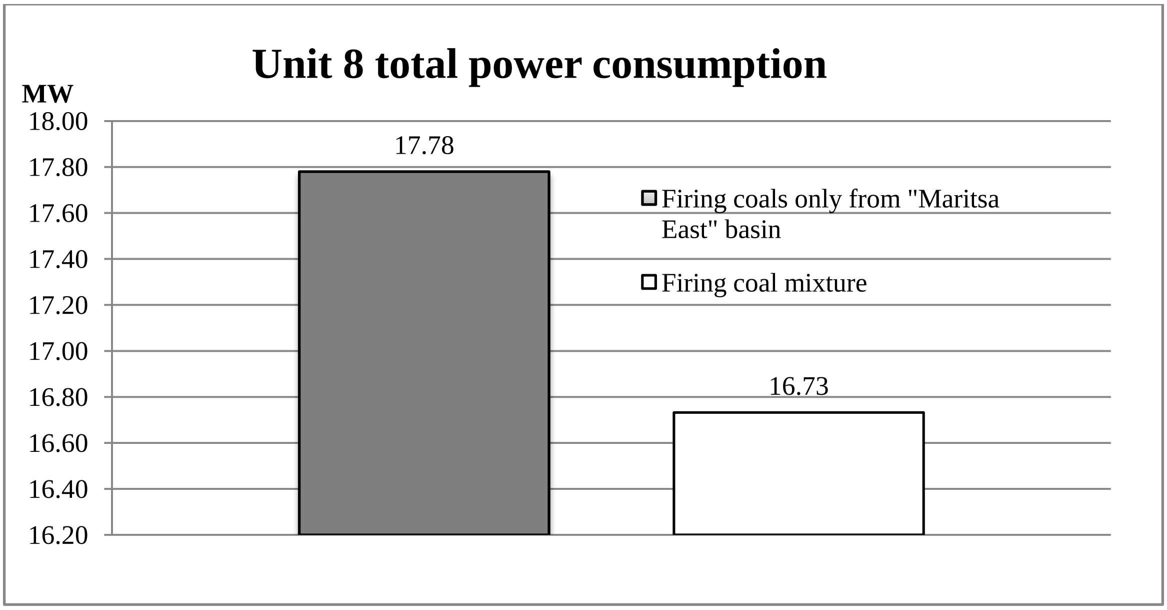

Fig. 11. Total power consumption for milling depending on the coal

4. Discussion

Based on the results from the tests the following summaries can be made:

4.1. Combustion tests with a single kind of coals and mixtures of different kinds of coals are performed. The ratios of the blends subject to the investigations are:

- 10% coals from “Pernik” basin + 90% coals from “Maritsa East” basin;
- 15% coals from “Pernik” basin + 85% coals from “Maritsa East” basin;
- 20% coals from “Pernik” basin + 80% coals from “Maritsa East” basin;
- 25% coals from “Pernik” basin + 75% coals from “Maritsa East” basin.

4.2. Adding coals from the "Pernik" basin results in changes such as:

- Increasing of the temperatures of the circulating flue-gas;
- Practically it can be assumed that with the same temperature of the flue-dust the ventilation efficiency of the mills remains the same during the two operational conditions;
- The amount of coals handled by one CPS increases with around 15% when firing coal mixtures. The reason is the lower moisture content and the increased temperatures of the drying agent;
- A small decrease of the R_{1000} and an increase of R_{90} is present when firing coal mixtures. This means that the coefficient of polydispersion of the particle size distribution is increasing.

4.3. The feasibility of the boiler can be assigned as a main indicator for its operation. The results are showing higher values (with around 0,3%) when firing coal blends.

4.4. Another important indicator is the change of the temperatures by levels in the combustion chamber. On Figure 5 is shown that no major changes have occurred. However it can be noted that:

- When firing coal mixtures from "Maritsa East" and "Pernik" basins an increase of the temperatures on level 13 (main combustion zone) is not present. On the contrary – a decrease of 67^oC is observed;
- An increase of the temperatures is present on level 33 and higher (around 40^oC).

4.5. Significant variations for the values of CO are not observed. An assessment of the change of the emission of the pollutants in regard of SO_2 and NO_x concentrations is performed and:

- Figure 7 shows a clear tendency of reduction of the SO_2 emissions when firing coal mixtures. The average value decreases with 2636 mg/Nm^3 – Figure 8;
- The variations of the NO_x emissions for the two operational conditions are given on Figure 9. An increase of the concentration of the nitrogen oxides is present when firing coal blends. The average increase during the tests is around 109 mg/Nm^3. The higher nitrogen content in the coals from the "Pernik" basin explains this fact.

4.6. The operation of FGD 8 when firing coal mixtures is defined by a lower limestone slurry consumption. The total decrease of the limestone slurry flow is around 25% compared to the operational conditions when firing coals only from the "Maritsa East" basin.

4.7. The power consumption of the Unit decreases with around 0,7% when firing coal mixtures from the "Maritsa East" and 'Pernik" basins compared to firing coals only from the "Maritsa East" basin.

Firing coal blends from the two basins is a viable option and its positive aspects are listed in p. 4.1.÷4.7.

5. Conclusions

However firing mixtures with more than 10÷15% coals from the "Pernik" basin is not recommended because:

5.1. The nitrogen oxides on the outlet of the boiler increase significantly and there is a danger for the environmental norms of 500 mg/Nm^3 to be exceeded.

5.2. Adding higher amount of coals from the "Pernik" basin into the mix will lead to operation with 4 CPS which is unacceptable from safety point of view.

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