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THE STATE OF AIR POLLUTION IN KRAGUJEVAC CAUSED BY THE OPERATION OF ENERGETIKA, LLC

Abstract: *Clean air is the foundation of healthy living and well-being of all living creatures on our planet. The presence of suffocating, poisonous, cancerous, irritant, as well as greenhouse gases in the atmosphere in all developed countries is strictly controlled as an important parameter of environmental quality. The actual state of air quality in Kragujevac, one of the largest urban areas in Serbia, has to be made known, and so do the possible activities to improve the situation. This paper gives an insight into the current state of operation regimes for the boilers of the company Energetika, LLC, Kragujevac, by far the largest emitter in the area, and showcases the possibility of reducing the emissions of flue gases by optimizing the combustion process in the said boilers. A number of additional aggravating circumstances related to the central heating system in Kragujevac, which will be presented in this analysis, are not the reason not to form a clear strategy for a significant reduction of emissions of flue gases from Energetika, LLC.*

Keywords: *emission, air quality, central heating systems, boiler facilities, clean cities*

1. INTRODUCTION

The emission of harmful combustion products (CO_2, CO, SO_2, NO_x, ash, etc.) is one of the areas in which more restrictive legal regulations are implemented at a fast rate worldwide, forcing the emitters of these substances to upgrade, rationalize, or completely change their methods of thermal energy production. In most developed countries a special tax has been imposed on carbon dioxide (CO_2) emissions, which significantly increased the number of studies on alternative renewable energy sources (solar, geothermal, wind, water, etc.) [1].

In Serbia, there is fairly strict legislation on the emissions of harmful combustion products. However, the sum of unfavourable circumstances makes the actual situation very unsatisfactory: intense combustion of low-quality domestic coal, combustion of heavy oils with high sulphur content, lack of quality measuring equipment, lack of regulations regarding the financing of periodic testing (the polluter pays for the measurement directly to the institution that conducts the measurement), and lack of legal regulations that restrict energy consumption, composition of used fuel, minimum efficiency of the plant, and cheap electrical energy [2].

Already within the initial consideration of the possible problems related to the emission of exhaust gases can it be concluded that Kragujevac is in a particularly difficult position. This is the only large city in Serbia that uses coal with low calorific value and high ash content as the primary energy source for the central heating system. Energetika, LLC consumes on average more coal than all the other heating plants in Serbia together – as much as ca. 100,000 tonnes per year over the past ten years.

2. CHARACTERISTICS OF BOILERS AT ENERGETIKA, LLC IN TERMS OF FLUE GAS EMISSIONS

Energetika, LLC is the largest district heating plant in the Balkans, with approximately 370 MW of thermal power in its boiler facilities. The boiler facilities are distributed at the following locations: company headquarters, Clinical Centre, Erdoglija, Central Workshop, and Stanovo.

At the headquarters site, within the complex of the former "Zastava" factory, there are five boiler facilities (a sixth is under construction, which has been suspended for some time now), whose main characteristics are given in table 1.

Table 1 *- Main characteristics of boilers at Energetika, LLC headquarters [3]*

Boiler	*Nominal power, MW*	*Fuel*	*Age*
K1	31.65	gas	40
K2	31.65	gas	40
K3	63.3	coal	33
K4	61.5	coal	28
K5	115.18	coal	23

All five steam generators produce superheated water vapour with the pressure of 35-38 [bar] and the temperature of 450 °C. Thus, this is a fluid whose high energy parameters indicate that these boilers are designed to operate in conjunction with steam (condensation) turbine and a generator of electricity. Energetika, LLC has two steam turbines with the nominal power of 10 and 20 MW, whose input operating parameters correspond to the output parameters of boilers. As the installed turbines have never been used for the production of thermal energy (steep price of electricity), there are huge energy losses because the water vapour with such high parameters is suppressed if necessary, and, as regards the central heating system, it is sometimes condensed to the state of boiling water.

Steam boilers K1 and K2 are the most reliable boilers at Energetika, LLC headquarters, because they use natural gas as the fuel. In terms of flue gas emissions, these boilers are the brightest spot of the entire heating plant.

Steam boilers K3 and K4 have identical constructions and since they can also use very low-quality coal as a fuel, they have been utilized the most over the recent years to maintain the operation of the district heating system in Kragujevac. They are wall-hung boilers that burn suspended coal dust with frontal burners (V-flame) designed for medium-quality coal combustion. Boilers K3 and K4 emit the highest percentage of ash into the smoke tract (as well as over 80% of total ash), which makes them unsuitable for urban environments, such as the City of Kragujevac.

Steam boiler K5 is the boiler with a vertical cyclone (membrane) furnace, which is the most recent addition to Energetika, LLC headquarters. Due to the lack of high-quality coal in the Serbian market in recent years, which is necessary for the boiler to work properly, K5 was rarely operational. All emission-related problems of boilers K3 and K4 also apply to K5, except that the latter has a more modern construction and a higher degree of usefulness, with a newer and upgraded electrostatic precipitator. Of course, the main issue is still the type of fuel – coal.

The heating plant Hospital is located at the Clinical Centre Kragujevac and it consists of five boiler facilities, whose main characteristics are given in table 2.

Table 2 *- Main characteristics of boilers at the Clinical Centre* [3]

Boiler	*Nominal power, MW*	*Fuel*	*Age*
K1b	6.6	gas	24
K2b	6.6	gas	25
K3b	7.3	gas	25
K4b	2.6	gas	32
K5b	7.0	gas	22
K6b	7.5	gas	5

Combustion of gas fuel can be achieved with the highest level of efficiency of the boiler (over 90%), and the products of combustion are loaded only with nitrogen oxides, of course, provided that all boilers of Energetika, LLC are working in optimal mode, which requires the measurement of O_2 and CO_2 in the flue gases. Not a single boiler at any of the locations is equipped with functioning equipment that measures these combustion products.

The heating plant Erdoglija is connected with the heat pipeline from the headquarters, to offset network losses. This location also stores a 7 MW hot water boiler using heavy fuel oil and two new boilers with combined burners, each powered with 15 MW (since 2009). In the 2003/2004 heating season, a gas burner was attached to the boiler that uses heavy fuel oil, so the boiler worked on gas fuel, which was an important step for reducing emissions of harmful exhaust gases. However, because of outstanding gas debt, the combustion of heavy fuel oil was reintroduced, which was also the case for the 2013/2014 season.

The heating plant Central Workshop has the capacity of 15 MW, and the plant Stanovo the capacity of 5 MW. Both heating plants can use heavy fuel oil and gas (they were put into operation in 2009).

3. LEGISLATION ON FLUE GAS EMISSIONS FROM BOILER FACILITIES

Regarding the legislation on flue gas emissions from boiler facilities, the act currently in force is the Regulation on Limit Emission Values of Air Pollutants, published in the Official Gazette of the Republic of Serbia, № 6/2011. The limitations in the Regulation pertaining to the existing (if they had been in operation for more than 20 years on the date this regulation entered into force) and to the new medium (thermal capacity from 1 to 50 MW) and large (thermal capacity greater than 50 MW) boiler facilities are given in tables 3, 4, 5, 6, 7 and 8.

Table 3 *- Boilers using solid fuels, existing (new) facilities, 1-100 MW [4]*

Pollutants	*Emission limit value for existing (new) boiler facilities, mg/m³*	
	Thermal capacity 1-50 MW	*Thermal capacity 50-100 MW*
Particulate matter	100 (50)	100 (50)
CO	250 (150)	250 (250)
SO_2	1700 (1300)	2000 (850)
$NO_x(NO_2)$	650 (500)	600 (400)

Table 4 *- Boilers using solid fuels, existing (new) facilities, > 100 MW [4]*

Pollutants	*Emission limit value for existing (new) boiler facilities, mg/m³*	
	Thermal capacity 100-500 MW	*Thermal capacity > 500 MW*
Particulate matter	100 (30)	50 (30)
CO	250 (250)	250 (250)
SO_2	-4x*+2400 (200)	400 (200)
$NO_x(NO_2)$	600 (200)	200 (200)

* x – boiler facility thermal capacity in MW

Table 5 *- Boilers using fuel oils, existing (new) facilities, 1-100 MW [4]*

Pollutants	*Emission limit value for existing (new) boiler facilities, mg/m³*	
	Thermal capacity 1-50 MW	*Thermal capacity 50-100 MW*
Particulate matter	50 (50)	50 (50)
CO	175 (80)	175 (175)
SO_2	1700 (850)	1700 (850)
$NO_x(NO_2)$	250 (200)	450 (400)

Table 6 *- Boilers using fuel oils, existing (new) facilities, > 100 MW [4]*

Pollutants	*Emission limit value for existing (new) boiler facilities, mg/m³*	
	Thermal capacity 100-500 MW	*Thermal capacity > 500 MW*
Particulate matter	50 (30)	50 (30)
CO	175 (175)	175 (175)
SO_2	-6.5x*+3650 (200)	400 (200)
$NO_x(NO_2)$	450 (200)	400 (200)

* x – boiler facility thermal capacity in MW

Table 7 *- Boilers using gaseous fuels, existing (new) facilities, 1-300 MW [4]*

Pollutants	*Emission limit value for existing (new) boiler facilities, mg/m³*	
	Thermal capacity 1-50 MW	*Thermal capacity 50-300 MW*
Particulate matter	5 (5)	5 (5)
CO	100 (80)	100 (100)
SO_2	35 (10)	35 (35)
$NO_x(NO_2)$	200 (200)	300 (150)

Table 8 *- Boilers using gaseous fuels, existing (new) facilities, > 300 MW [4]*

Pollutants	*Emission limit value for existing (new) boiler facilities, mg/m³*	
	Thermal capacity 300-500 MW	*Thermal capacity > 500 MW*
Particulate matter	5 (5)	5 (5)
CO	100 (100)	100 (100)
SO_2	35 (35)	35 (35)
$NO_x(NO_2)$	300 (100)	200 (100)

For the combustion of suspended coal dust and for dry ash draining, the oxygen content in the flue gases should be O_R = 6%. For boilers that use liquid and gaseous fuels, oxygen content in the flue gases should be O_R = 3%. In case the measured oxygen content is different from the abovementioned values, the measured emission of the flue gas is first converted according to the equation (1), and then compared with the values given in the table below:

$$E_R = E_M(21- O_R)/(21- O_M), \quad (1)$$

where:
E_R and E_M, mg/m^3 – reference and measured emissions of the observed combustion product and
O_R and O_M [%] – reference and measured oxygen content in the flue gases.

The smoke number is the degree of opacity of the surface of the filter paper, which is caused by waste gases from plants that use liquid and gaseous fuels. It is expressed on a ten-point scale from 0 to 9 for different degrees of opacity (Bacharach scale). The smoke number for heavy fuel oils is up to 2, for light fuel oils up to 1, while for gas fuels it is up to 0.

4. AVAILABLE MEASUREMENT DATA ON FLUE GAS EMISSIONS FROM THE BOILER FACILITIES AT ENERGETIKA, LLC

During the 2008/2009 heating season, the Faculty of Mechanical Engineering (Laboratory for Thermodynamics), University of Kragujevac, used a modern digitalized analyzer for combustion products, IMR 2800P, and recorded emissions from the boilers of Energetika, LLC at the company headquarters, at the Clinical Centre, and at Erdoglija location. The measurements involved 11 boilers from Energetika, LLC. Tables 9, 10, and 11 present the measured and calculated data for these boilers. The load of the boiler (%) is given in relation to the nominal power (not measured).

Measurement points from which data on the emissions from boilers with complex structures were collected at Energetika, LLC headquarters were located directly behind the air heater.

Table 9 - *Emissions from boilers at Energetika, LLC headquarters*

Boiler	Thermal capacity, MW	Fuel	Load, %	CO, mg/m^3	SO_2, mg/m^3	NO_2, mg/m^3
K1	31.65	gas	100	0	0	65 (234)*
K2	31.65	gas	100	0	0	77 (231)*
K3	63.3	coal	100	3514 (8641)*	666 (1638)*	160 (393)*
K4	61.5	coal	100	176 (406)*	603 (1392)*	201 (464)*
K5	115.18	coal	50	0	1533 (4339)*	138 (391)*

* Relevant emissions values reduced to the prescribed oxygen content according to equation (1)

Table 10 - *Emissions from boilers at the Clinical Centre location*

Boiler	Thermal capacity, MW	Fuel	Load, %	CO, mg/m^3	SO_2, mg/m^3	NO_2, mg/m^3
K1b	6.6	gas	100	0	0	208 (201)*
K2b	6.6	gas	100	0	0	205 (202)*
K3b	7.3	gas	100	5000	1336	245
K4b	2.6	gas	100	0	0	213 (206)*
K5b	7.0	heavy fuel oil	50	6	3564 (3412)*	470 (450)*

Table 11 - *Emissions from boilers at Erdoglija location*

Boiler	Thermal capacity, MW	Fuel	Load, %	CO, mg/m^3	SO_2, mg/m^3	NO_2, mg/m^3
K1e	7.0	Fuel oil	100	0	2614 (3337)*	422 (539)*

Measurements of ash emissions were performed in 2009 (at the request of Energetika, LLC) by the Institute for Occupational and Environmental Quality "Prvi maj" Niš, by means of Šterlain equipment, at maximum loading of boilers K3 and K4 at Energetika, LLC headquarters. Measurements showed that the emissions of fly ash (when Pljevlja lignite was used) for boiler K3 were 22 times greater than the allowed 2200 mg/m^3, and as much as 46.5 times greater for boiler K4. The measured degrees of ash separation by electrostatic precipitators in boilers K3 and K4 were 97.5% and 94.9%, respectively.

A somewhat disconcerting fact is that the use of Pljevlja lignite as the fuel (which is one of the better quality coal types used in the boilers of Energetika, LLC) at an assumed efficiency of 99% of the electrostatic precipitator for ash emissions, would amount to 900 mg/m^3, which is nine times higher than the amount permitted by the law. Thus, with combustion of these fuels it is practically impossible to ensure compliance with legal requirements.

Although the available measurement data on the emission of flue gases from the boiler facilities of Energetika, LLC date back to 2009, in terms of emissions, the situation did not change in 2014, as well. This is because there was no investment in the upgrade of boiler facilities, and since low-quality coal (lignite) with high ash content (twice higher) had been increasingly used during the previous years, the degradation of available electrostatic precipitators was further accelerated. This is evidenced by the results of air pollution measurements in the City of Kragujevac during a winter month (December), compared to a summer month (August) in 2014, conducted by the Institute of Public Health Kragujevac (Table 12).

Table 12 - *Mean emissions of pollutants in Kragujevac, December and August 2014 [5]*

Measurement points (parts of the city)	*SO_2, µg/m^3 GVE 50 µg/m^3*			*NO_2, µg/m^3 GVE 85 µg/m^3*			*PM, µg/m^3 GVE 50 µg/m^3*		
	*12.**	*08.***	*R****	*12.**	*08.***	*R****	*12.**	*08.***	*R****
Čistoća	4	3	1	20	16	4	30	13	17
Štafeta	7	4	3	16	15	1	30	12	18
Ilićevo	3	1	2	16	15	1	24	6	18
Airport	3	2	1	17	9	8	10	6	4
Brewery	4	2	2	19	11	8	31	11	20

** 12 – December 2014; ** 08 – August 2014; *** R – differences in emissions*

Table 12 shows that the mean values of the emissions of pollutants in Kragujevac during December and August 2014 were above the legally permitted emission limit values (ELVs). The daily values of sulphur dioxide (SO_2) during these months did not exceed the maximum allowable ELV of 125 µg/m^3. Maximum values were measured at the measurement point "Štafeta monument" – 17 µg/m^3 (4 Aug 2014) and 16 µg/m^3 (1 Dec 2014).

The daily values of nitrogen dioxide (NO_2) during these months exceeded the legally permitted ELV of 85 µg/m^3. Maximum measured values were 32 µg/m^3 at the measurement point "Štafeta monument" (12 Aug 2014) and 70 µg/m^3 at the measurement point "Ilićevo" (15 Dec 2014), while the tolerance threshold for nitrogen dioxide was 40 µg/m^3.

Daily values of particulate matter (PM) during August 2014 exceeded the legally permitted ELV of 50 µg/m^3. The maximum measured value was 40 µg/m^3 (05 Aug 2014) at the measurement point "Štafeta monument". In December 2014, the values of particles were above the allowed ELVs on 14 days. The maximum measured value was 87 µg/m^3 (30 Dec 2014) at the measurement point "Čistoca", where the values exceeded the allowed ELVs on six days. At the measurement points "Ilićevo" and "Brewery", there were three days during December with values above the ELVs, while at the measurement point "Štafeta monument" the values exceeded the ELVs on two days.

The daily values of pollutant emissions in Kragujevac reveal that the emissions of sulphur dioxide and nitrogen dioxide do not vary considerably during the year, which is not the case with particulate emissions. A significant increase in particulate emissions during the

winter months is due to the combustion of large amounts of low-quality coal in the boilers of Energetika, LLC (located in the urban area of the City of Kragujevac).

Table 13 presents the results of measurements of the total deposited matter in Kragujevac in a winter month (December) compared to a summer month (August) 2014, conducted by the Institute of Public Health Kragujevac.

Table 13 *- Concentrations of total deposited matter in Kragujevac, December and August 2014 [5]*

Measurement points	*Total deposited matter [mg/m^2/day]*		
	December 2014	*August 2014*	*Diff. in emissions*
Save Kovačevića Str.	**612.73**	117.05	495.68
Bus station	**601.72**	107.28	494.44
Bresnica–school	447.24	88.30	358.94
Ilićevo–nursery	322.93	233.10	89.83
Stanovo–brickyard	189.71	86.27	103.44
Čistoća–public utility	407.10	114.69	292.41
Mean	**430.24**	124.45	305.79

The measured values of the total deposited matter in December (Table 13) exceeded the ELV of 450 mg/m^2/day at two locations. The maximum value of 612.73 mg/m^2/day was measured at the measurement point at Save Kovačevića Street in downtown Kragujevac. The mean monthly value of total deposited matter emissions was 430.24 mg/m^2/day in December, which was above the allowed value for urban environments of 300 mg/m^2/day.

In August, total deposited matter did not exceed the ELV. The maximum value of 233.10 mg/m^2/day was measured at the measurement point Ilićevo (nursery). The average monthly value of the emissions of total deposited matter in August was 124.45 mg/m^2/day and did not exceed the allowed levels for urban areas.

The results of measurement of total sediment substances in the city of Kragujevac revealed a devastating fact that Energetika, LLC is a major air polluter during the winter months. This can be said with certainty, even though no measurements of emissions from individual furnaces were performed, because the measurement results showed that the values of total deposited matter at the measurement points Save Kovačevića Street and the bus station, near the boilers at Energetika, LLC headquarters (boilers K3 and K4, which use low-quality coal) were the highest (although there is a developed district heating system in this area), while the values of total deposited matter were the lowest at the measurement points Stanovo–brickyard and Ilićevo–nursery. The latter measurement points are located far from the boilers although there is no developed district heating system in the area (individual heaters are prevalent).

5. CONCLUSION

Institute for Public Health has been conducting regular air monitoring in the City of Kragujevac since 1975. Based on available data on measured emissions in Kragujevac, it can be concluded that the dominant source of air pollution during the heating season is Energetika, LLC, whose boilers use solid fuels with a lot of ash as well as liquid fuels with high sulphur content. Boilers that use gaseous fuels (primarily natural gas) are much smaller sources of air pollution in Kragujevac, but Energetika, LLC has not used them for the district heating system in recent years, due to outstanding gas debt.

Air pollution produced by the boiler facilities of Energetika, LLC in Kragujevac can be reduced by:

- Encouraging regular and adequate maintenance of boiler facilities, because it would significantly reduce their emissions and increase energy efficiency.
- Increasing the use of the existing boilers K1 and K2 at Energetika, LLC headquarters, as they have been reconstructed to work on gas fuel (which would substantially reduce particulate matter emissions).
- Replacing the old coal-fired boilers with new and more efficient gas-fired boilers at Energetika, LLC headquarters, which would require about €4 million [7]. This is

presently not feasible considering the economic situation in Kragujevac and in Serbia.

Yet, the question remains why the large-capacity boiler facilities of Energetika, LLC, designed for coal dust combustion, were placed in the centre of a large urban area, such as the City of Kragujevac.

REFERENCES:

[1] Biočanin, R. (2009). *Environmental Protection and Improvement*, scientific books, Faculty of Pedagogy, Užice, 55-73.

[2] Aksentijević, S., Milutinović, S. (2006). *Improving the System of an Environment Polluted by Fossil Fuels*, Quality festival, Kragujevac.

[3] Government of the Republic of Serbia, (2011). *Regulation on Emission Limit Values of Air Pollutants*, Official Gazette of the Republic of Serbia, № 6/2011, Belgrade.

[4] Department for Spatial Planning, Construction, and Environmental Protection of the City of Kragujevac, (2014). *Ecological Bulletin*, No. 8 and 12, Kragujevac.

[5] Institute for Public Health Kragujevac, (2015). *Annual Results of Air Quality Control in 2014*, Kragujevac.

[6] Trifunović, S. (2013). *Study on the Past, Present and Future Environmental Planning in the City of Kragujevac and the Surrounding Area*, Eko centar, Kragujevac.

[7] www.energetika-kragujevac.com