FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 17, Nº 2, 2020, pp. 131 - 137
https://doi.org/10.22190/FUWLEP2002131S

SO_2 CONCENTRATIONS IN BOR, SERBIA, IN THE PERIOD 2011-2020

UDC 546.224-31:669.333.046.5:504.5(497.11Bor)"2011/2020"

Aleksandar Simonovski[1], Viša Tasić[1], Tatjana Apostolovski-Trijić[1], Nevena Milikić[1], Aca Božilov[2]

[1]Mining and Metallurgy Institute Bor, Serbia
[2]University of Niš, Faculty of Occupational Safety in Niš, Serbia

Abstract. *In this paper, the analysis of SO_2 concentrations in the Bor town (Serbia) is presented for the 2011-2020 period. The results of measurements from the period of operation of the old copper smelter (2011-2015) were compared with the results of measurements during the period of operation of the new copper smelter (2016-2020). As a result of changes in the copper smelting technology and the better treatment of waste gases in the smelter, on average, the level of SO_2 was reduced by 67% in the 2016-2020 period compared with the SO_2 level in 2011-2015. The presence of a weak ($r<0.4$) Pearson correlation between the SO_2 levels among the sampling points were determined in both periods of observation.*

Key words: *sulfur dioxide, monitoring, air pollution, copper smelter*

1. INTRODUCTION

The Municipality of Bor is located in Europe on the Balkan Peninsula in the east of the Republic of Serbia. With about 50000 inhabitants in urban and rural settlements, the Municipality of Bor has been the major centre of copper and other precious metals mining and processing for more than a century [1].

The waste gas emissions from the copper smelter were a major environmental problem for the region. For example, in 2002, the copper smelter emitted approximately 70000 tons of sulphur dioxide, several hundred tones of heavy metal-contaminated particulates, 360 tones of arsenic, 83 tons of lead, 830 tons of zinc and 0.1- 0.2 tones of mercury. These numbers are, nevertheless, lower than the levels of emissions in 1990, during which approximately 250000 tones of sulphur dioxide, 1000 tones of heavy-metal contaminated particulates, 1000 tones of arsenic, 500 tons of lead, 2500 tons of zinc and 1.6 tones of mercury, were emitted annually [2].

Received September 11, 2020 / Accepted October 15, 2020
Corresponding author: Aleksandar Simonovski
Mining and Metallurgy Institute Bor, Zeleni bulevar 35, 19210 Bor, Serbia
E-mail: sim_aca@yahoo.com

The technology of processing the copper concentrates in the copper smelter in Bor was obsolete and, therefore, it was changed in 2016 when the new copper smelter and the sulphuric acid factory started with operations. By introducing the new copper-smelting technology, the emissions of SO_2, PM, and other pollutants comprising the smelter waste gas streams, has significantly reduced.

SO_2 is one of the most important environmental polluters. The SO_2 can react with other compounds in the atmosphere to form small particles. These particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory diseases, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death. That is the main reason why the impact of SO_2 from the copper smelter in Bor has been the subject of many studies [1-6]. According to national legislation [7], to protect human health, the allowed daily concentration for SO_2 is set to 125 µg/m^3, and may not be exceeded more than 3 times in one calendar year. The annual limit value for sulphur dioxide concentration is 50 µg/m^3.

The primary goal of this research was to compare levels of SO_2 in the periods before and after the construction of the new copper smelter in Bor. In that aim, the results of measurements in 2011-2015 (old smelting technology) were compared with the results for the 2016-2020 period (new smelting technology).

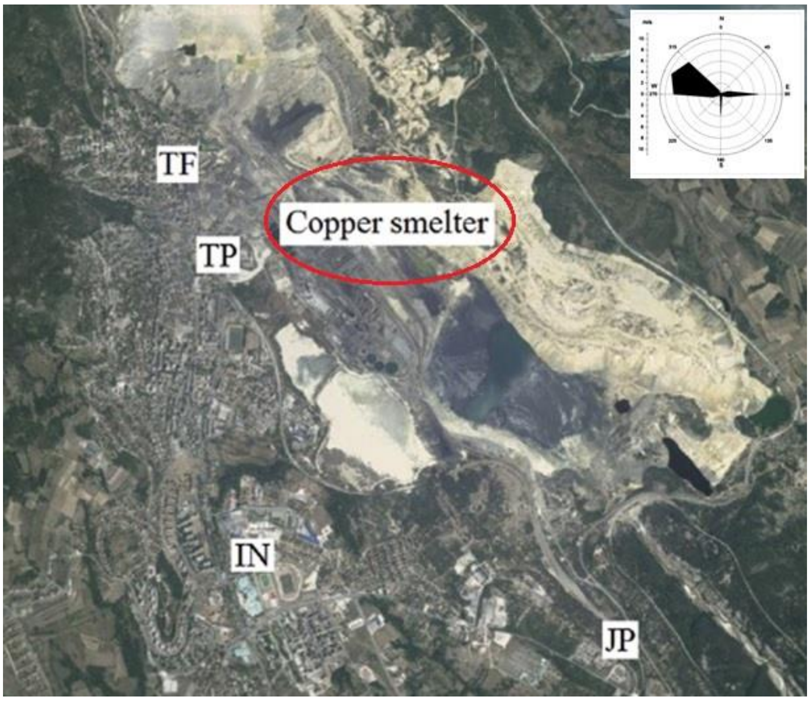

Fig. 1 Sampling locations in the Bor town urban areas relative to the copper smelter facilities (1. Technical Faculty in Bor -TF, 2. Town Park -TP, 3. Mining and Metallurgy Institute Bor - IN, 4. Jugopetrol - JP)

2. MATERIALS AND METHODS

Results presented in this paper were obtained from the regular sampling campaigns conducted from January 2011 to June 2020 at four locations in the Bor town urban area (Technical Faculty in Bor - TF, Town Park - TP, Mining and Metallurgy Institute Bor - IN, and Jugopetrol - JP) as shown in Figure 1. The SO_2 samples were collected on a daily bases. In total, 3440 daily samples were collected per each sampling point. Sampling campaigns were conducted by the Mining and Metallurgy Institute Bor, Department for Chemical and Technical Testing, following the state and municipal monitoring program.

2.1. Sampling locations

The sampling point TF is located close to the Technical Faculty in Bor, about 1 km N-NW relative to the copper smelter. The sampling point TP is located close to the Town Park in Bor, about 1 km W relative to the copper smelter. The sampling point IN is located close to the Mining and Metallurgy Institute Bor, about 2 km S-SW from the copper smelter. The sampling point Jugopetrol is located close to the former Jugopetrol warehouse, about 2.5 km S-SE from the copper smelter.

The dispersion of air pollutants is strongly affected by wind speed and direction, which influences the spreading of air pollutants over Bor town urban areas [4]. The direction and the strength of the wind in the period from 2011 to 2020 were mostly towards W–NW and partially towards E and S which can be seen from the wind rose shown in Figure 1.

2.2. Sampling equipment and procedures

A sampling of sulfur dioxide is carried out by absorbing the contaminant from known air volume in the appropriate absorption solution, using a device AT-801X-PE [8]. Samples were collected on a daily basis (9 AM - 9 AM). Sulfur dioxide test method was SRPS ISO 4220: 1997 - Determination of the index of acidic gaseous pollutants in the air (titrimetry). The detection limit for that technique was less than 0.01 ppm.

3. RESULTS AND DISCUSSION

The average daily SO_2 levels in the observed periods are shown as box-plots in Figure 2 and Figure 3. SO_2 concentrations at sampling point TF are on average about 67% lower in the 2016-2020 period compared with SO_2 concentrations in the 2011-2015 period. Similarly, SO_2 concentrations at sampling point TP, IN, and JP are 82%, 73%, and 46% lower in 2016-2020 compared with those concentrations in 2011-2015. Such a decrease is a consequence of new technology for copper smelting and the better treatment of waste gases in the copper smelter.

Sampling points TF, TP, and JP are at the dominant wind directions relative to the copper smelter whilst sampling point IN is not, meaning that IN site is least impacted by waste gasses emissions from the copper smelter facilities [1, 9]. Annual SO_2 levels and number of days with SO_2 concentrations above daily limit value are shown in Table 1.

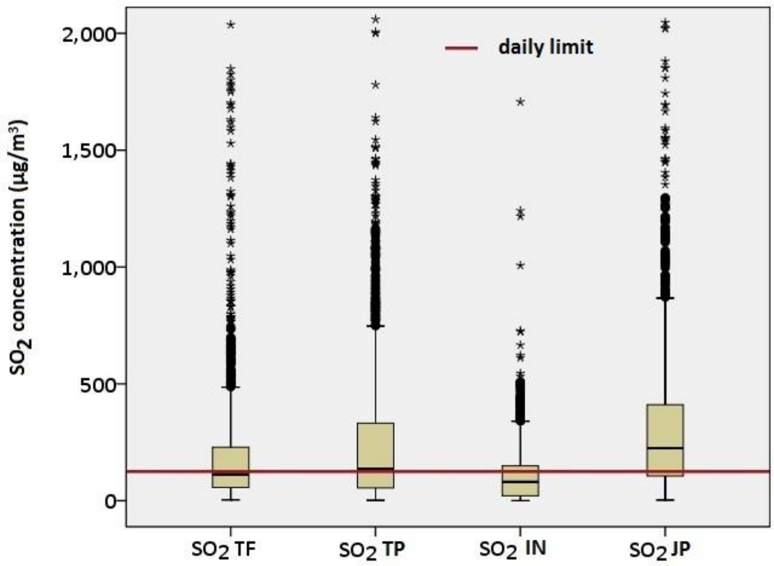

Fig. 2 Box plots of average daily concentrations of SO_2 in Bor in the 2011-2015 period

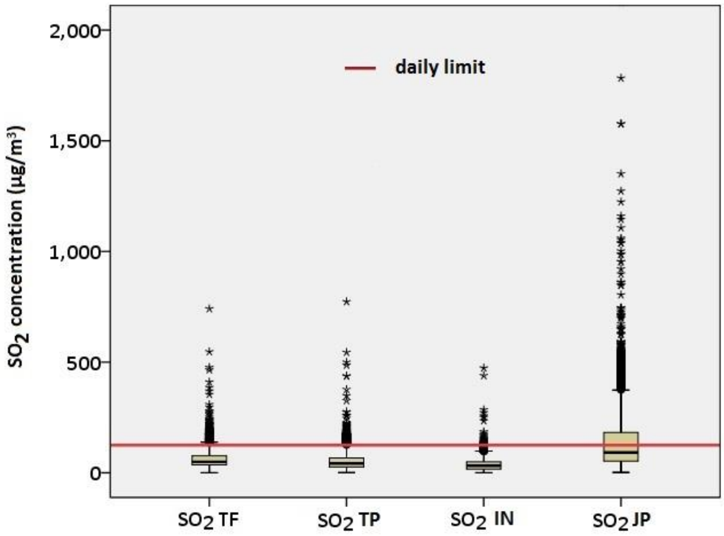

Fig. 3 Box plots of average daily concentrations of SO_2 in Bor in the 2016-2020 period

Table 1 Average annual levels of SO_2 (μg/m^3) in Bor, and number of days with SO_2 concentrations above the daily limit in the period January 2011 - June 2020 (LV - annual limit value, ADLV - number of days with SO_2 concentrations above daily limit value)

Old smelter operation period								
Year	TF SO_2	TF ADLV	TP SO_2	TP ADLV	IN SO_2	IN ADLV	JP SO_2	JP ADLV
2011	250.8	156	199.2	163	74.3	68	284.3	138
2012	230.5	163	211.7	151	89.6	94	290.6	201
2013	89.9	95	227.5	172	84.3	74	184.6	195
2014	123.2	133	321.3	245	127.1	176	273.7	245
2015	92.2	94	240.8	204	145.8	169	262.9	214
LV	50	3	50	3	50	3	50	3
New smelter operation period								
Year	TF SO_2	TF ADLV	TP SO_2	TP ADLV	IN SO_2	IN ADLV	JP SO_2	JP ADLV
2016	56.4	17	48.5	19	44.8	3	133.9	119
2017	49.5	17	43.7	12	43.1	4	132.8	112
2018	52.1	12	47.0	13	20.0	0	108.1	99
2019	83.2	47	55.0	41	28.0	8	176.6	140
2020*	110.6	27	75.5	22	35.1	6	288.6	76
LV	50	3	50	3	50	3	50	3

* Data presented for the period January - June 2020

The results presented in Table 1 clearly show the improvement in air quality concerning SO_2 concentrations in the urban areas in Bor in the period of the new smelter operation (2016-2020). Unfortunately, the annual SO_2 concentrations at the suburban-industrial site JP are still unacceptably high. Also, the number of days with SO_2 concentrations above the prescribed daily limit in the 2016-2020 period at all sampling points is lower but still unacceptably high except for sampling point IN. The average annual concentrations of SO_2 in Bor are the highest in the Republic of Serbia and Europe as well [10-12]. Such results point out the fact that the problem of air pollution with SO_2 in Bor is only partly solved by putting in the operation of the new smelter and sulphuric acid factory. The new efforts and resources should be engaged to cover all the SO_2 emission sources within the smelter with the proper waste gasses cleaning systems.

Pearson correlation coefficients between the average daily SO_2 concentrations at sampling sites in Bor in 2011-2015 (old smelting technology) and 2016-2020 (new smelting technology) are shown in Table 2. The presence of a weak ($r<0.4$) Pearson correlation between the SO_2 levels among the sampling points were determined in both periods of observation. Such correlation values indicate that air pollution with SO_2 strongly depends on meteorological conditions. The dispersion of air pollutants in Bor is mostly affected by the direction and speed of the wind [1, 3, and 9]. These parameters didn't change significantly in the observed period, so that, the correlations of SO_2 levels between the sampling sites were not substantially altered.

Table 2 Pearson's correlation coefficients between the average daily SO_2 concentrations at sampling sites in Bor in the periods 2011-2015 and 2016-2020

Old smelter operation period				
	TF SO_2	TP SO_2	IN SO_2	JP SO_2
TF SO_2	1.00			
TP SO_2	.244**	1.00		
IN SO_2	.167**	.385**	1.00	
JP SO_2	.096**	-.026	.150**	1.00
New smelter operation period				
	TF SO_2	TP SO_2	IN SO_2	JP SO_2
TF SO_2	1.00			
TF SO_2	.312**	1.00		
IN SO_2	.299**	.181**	1.00	
JP SO_2	.311**	.114**	.339**	1.00

** Correlation is significant at the 0.01 level (2-tailed)

4. CONCLUSIONS

In this paper, the analysis of SO_2 concentrations in the Bor town (Serbia) is presented for the 2011-2020 period. The results of measurements from the period of operation of the old smelter (2011-2015) were compared with the results of measurements during the period of operation of the new smelter (2016-2020). As a result of changes in the copper smelting technology and the better treatment of waste gases in the smelter, on average, the level of SO_2 was reduced by 67% in 2016-2020. Such a decrease is a consequence of new technology for copper smelting and the better treatment of waste gases in the copper smelter. Unfortunately, the annual SO_2 concentrations at the suburban-industrial site JP are still unacceptably high. Also, the number of days with SO_2 concentrations above the prescribed daily limit in 2016-2020 at all sampling points is lower than in the 2011-2015 period, but still unacceptably high with the exception of sampling site IN. The problem of air pollution with SO_2 in Bor is only partly solved by putting in the operation of the new smelter and sulphuric acid factory. Thus, additional actions have to be done with the aim to cover all the SO_2 emission sources within the smelter with the proper waste gasses cleaning systems.

The presence of a weak (r<0.4) Pearson correlation between the SO_2 levels among the sampling points were determined in both periods of observation. Such correlation values indicate that air pollution with SO_2 strongly depends on meteorological conditions.

Acknowledgement: *This work is financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*
Contract about realization and financing of scientific research work in 2020 for Mining and Metallurgy Institute Bor, No. 451-03-68/2020-14/200052.

REFERENCES

1. V.Tasić, R.Kovačević, B.Maluckov, T.Apostolovski-Trujić, M.Cocić, B.Matić, M.Šteharnik, The content of As and heavy metals in TSP and PM_{10} near copper smelter in Bor, Serbia, *Water Air and Soil Pollution*, vol. 228:6, 2017.
2. UNEP, Clean-up of Environmental Hotspots, FRY; Assessment of Environmental Monitoring Capacities in Bor (2002); https://postconflict.unep.ch/publications/borcapacityassessmentseptember2002.pdf
3. S.Serbula, T.Kalinovic, J.Kalinovic, A.Ilic, Exceedance of air quality standards resulting from pyro-metallurgical reduction of copper: a case study, Bor (Eastern Serbia), *Environ. Earth Sci.*, vol. 68, no. 7, pp. 1989-1998, 2013.
4. R.Kovačević, M.Jovašević-Stojanović, V.Tasić, N.Milošević, N.Petrović, S.Stanković, S.Matić-Besarabić, Preliminary analysis of levels of arsenic and other metallic elements in PM_{10} sampled near copper smelter Bor (Serbia), *Chem. Ind. Chem. Eng. Q.*, vol.16, no.3, pp. 269−279, 2010.
5. M.Dimitrijević, A.Kostov, V.Tasić, N.Milošević, Influence of pyrometallurgical copper production on the environment, *J. Hazard. Mater.*, vol. 164, pp. 892–899, 2009.
6. Đ.Nikolić, N.Milošević, I.Mihajlović, Ž.Živković, V.Tasić, R.Kovačević, N.Petrović, Multi-criteria analysis of air pollution with SO_2 and PM_{10} in urban area around the copper smelter in Bor, Serbia. *Water Air Soil Pollut*. vol. 206 (1), pp. 369-383, 2010.
7. Official Gazette of RS (no. 75/10, 11/10 and 63/13) (2013). Regulation for the conditions and requirements for monitoring air quality https://www.paragraf.rs/propisi/uredba-uslovima-monitoring-zahtevima-kvaliteta-vazduha.html (accessed on August 28th 2020, in Serbian).
8. http://www.proekos.com/at801x.html (accessed on August 28th 2020, in Serbian)
9. V.Tasić, R.Kovačević, N.Milošević, Investigating the impacts of winds on SO_2 concentrations in Bor, Serbia. *J. sustain. dev. energy water environ. syst.* vol.1 (2), pp. 141-151, 2013.
10. http://www.sepa.gov.rs/download/izv/Vazduh2019_final.pdf (accessed on August 28th 2020, in Serbian)
11. http://www.sepa.gov.rs/download/izv/Vazduh2018_final.pdf (accessed on August 28th 2020, in Serbian)
12. http://www.sepa.gov.rs/download/izv/Vazduh2017_final.pdf (accessed on August 28th 2020, in Serbian)

KONCENTRACIJE SO_2 U BORU, SRBIJA, U PERIODU 2011-2020

U ovom radu prikazana je analiza koncentracija SO_2 u gradu Boru (Srbija) za period 2011-2020. Rezultati merenja iz perioda rada stare topionice bakra (2011-2015) upoređeni su sa rezultatima merenja iz perioda rada nove topionice bakra (2016-2020). Kao rezultat promena tehnologije topljenja bakra i boljeg tretmana otpadnih gasova u topionici, u proseku je nivo SO_2 smanjen za 67% u periodu 2016-2020 u poređenju sa nivoom SO_2 u periodu 2011-2015. U oba perioda posmatranja utvrđeno je prisustvo slabe ($r < 0.4$) Pearsonove korelacije nivoa SO_2 između tačaka uzorkovanja. Problem zagađenja vazduha sumpor-dioksidom iz pogona topionice bakra u Boru samo je delimično rešen puštanjem u rad nove topionice i fabrike sumporne kiseline. Iz tog razloga neophodno je preduzeti dodatne akcije s ciljem da se svi izvori emisije SO_2 u topionici obuhvate sistemima za tretman otpadnih gasova.

Ključne reči: *sumpor-dioksid, monitoring, zagađenje vazduha, topionica bakra*