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Estimates of Sulfur Dioxide Emissions from Lignite Power Plants in Kosovo

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ABSTRACT

The importance of energy in the economic development of countries in transition is almost vital, especially in countries with large coal mineral resources, such as our country, Kosovo. Quantification and accurate analysis of sulfur dioxide (SO_2) emissions from lignite power plants are done to inform environmental stakeholders, improve regulatory compliance, protect public health, improve emission control technologies, and support environmental practices. sustainable energy. This study investigated the quantification and accurate analysis of SO_2 emissions from lignite power plants to inform environmental stakeholders, improve regulatory compliance, protect public health, improve emission control technologies, and support sustainable energy practices. The laboratory analyses performed with standard methods have resulted in different values for the parameters: Moisture, ash, and sulfur content in lignite is up to 45%, 20%, and 1.2% during the year 2023, through these results we have calculated the SO_2 emission that resulting in an average value of 777.4 kg/h. The realized correlation o between the SO_2 emission and parameters such as Moisture, sulfur in lignite (total and organic), and High thermal, has increased the accuracy of SO_2 emission estimates, the components that are active components during the coal combustion process. Better estimates facilitate a more accurate assessment of the environmental impact of organic SO_2 emissions, such as their role in acid rain formation and ecosystem damage. This assessment reflects the poor state of current lignite combustion technologies and suggests their improvement in terms of controlling SO_2 emissions.

Keywords: energy, power-plants, lignite, emission, sulfur oxides.

INTRODUCTION

The term production of Absolutely Clean Energy does not exist, whether it comes from the sun, wind, water, or any other source, does not exist. There is practically no energy facility that does not have a certain impact on the environment. In the case of power plants, the impact on the environment is almost always negative, from direct environmental catastrophes such as oil spills, acid rain, and radioactive radiation to indirect consequences such as global warming and the like. The environmental impacts of combustion during the coal burning process cannot be ignored, especially when during this process the pollution caused is accompanied by the release of sulfur from the coal (Abelson, 1975; Davut and Sibel, 1997; Medunić et al., 2018b; Train, 1977). According to existing data, Kosovo has abundant sources of surface lignite, it is said that our country occupies the 4th or 5th place of the largest reserves in the world. Most of the reserves are located near the two main thermal power plants in Obliq very close to the capital of our country Pristina. The mine started working in 1922, and from that time until today 320 million tons of lignite have been extracted so far. The annual production is 8.5 million tons/year, approximately corresponding to the consumption of power plants Kosovo A and Kosovo B. A simple calculation shows that this can satisfy the demand for more than 1,000 years.

The current total power generation capacity in Kosovo is 1,054MW. The part of the energy generated by power plants is 974MW, while the rest generated by hydropower plants is 75MW. We also have a small power generation of 5 MW from some small hydropower plants and wind energy. Thus, most of the country's energy is generated by the Thermal Power Plant, i.e., Kosovo A and Kosovo B is more than 90% of the country's total energy. One of the main pollutants in the atmosphere that affects the environment is estimated to be sulfur dioxide (SO_2). Most of the sulfur dioxide released into the atmosphere is mainly from the combustion of sulfur content in fossil fuels. The health effects of exposure to high SO_2 levels are well-reported by many authors. (Seinfeld 1975; Scott et al. 2003).

Coal, a nonrenewable fossil resource, has been the main energy source for centuries (Çelik et al., 2019). The organic and inorganic structure of coal consists of minerals such as carbon, sulfur, clay, calcite, and quartz (Boylu and Karaağaçoğlu, 2018). The sulfur in coal occurs in organic and inorganic forms (Liu et al., 2020). Inorganic forms of sulfur in coal are generally found as pyrite, sulfur, and sulfate (Li and Tang, 2014). The chemical composition of coal is mainly a mixture of carbon and hydrogen atoms, sulfur atoms that are also trapped in coal, mainly in two forms. In one form, sulfur is a special particle often attached to iron (green sulfur, pyrite) without any connection to the carbon atoms, as in the center of the drawing (gold fools). In the second form, sulfur is chemically bonded to carbon atoms (organic sulfur).

The coal that has > 1% organic sulfur in its content is called high organic sulfur coal, and the organic sulfur content in super high organic sulfur coal exceeds 4% [Chou, 1997, 2012]. Sulfur oxides (SO_x) emissions during the production of electricity made by the combustion of lignite are a function of the sulfur content of the lignite and the composition of the lignite (i.e., the sulfur content, the heat value, and the alkali concentration). The conversion of lignite sulfur to SO_x is generally inversely proportional to the concentration of alkali compounds in lignite. The alkali content is known to have a major effect on sulfur conversion and acts as an integrated sorbent for the removal of SO_x.

The only characteristics of coal that greatly affect sulfur dioxide (SO_2) emissions are the total sulfur and ash content, and the amount captured by the ash is only a small fraction of the total. Most SO_2 is emitted or captured by the desulfurization of flue gases. The sulfur content in coal varies from less than 0.5% m/m to more than 10% m/m while those used for combustion are usually in the region of 0.5–3% m/m (Laban and Atkin, 2000). Sulfur is mainly associated with three phases in coal; sulfate minerals, sulfide minerals (mainly pyrite, FeS_2), and organic matrices. The sulfate content is usually low, except when pyrite is oxidized. Our knowledge of organic sulfur in coal is slightly less reliable (Davidson, 1994).

MATERIALS AND METHODS

Lignite used in electricity generation processes results in the emission of gaseous pollutants into the atmosphere, unless some of the emission reduction measures (primary, secondary) are implemented. The lignite combustion process creates gas products that can absorb solar energy and release heat to the earth's surface, resulting in rising earth temperatures, resulting in their impact on global warming. In table number 1 we will present the results of the initial analysis of Kosovo's Lignite.

Moisture, ash, and sulfur content in lignite is up to 45%, 20%, and 1.2% (Note: The sulfur content for calorific value is very high due to the low calorific value of lignite used in these plants). SO_2 emissions from coal combustion mainly depend on the sulfur content in the coal, unlike CO_2 and NO emissions which rely on the operating conditions and design of the plant.

The process of burning coal with powder in the boiler is a complex non-linear phenomenon. Pollutants emitted by power plants depend mainly on the characteristics of the fuel burned, the temperature of the furnace, the actual air used, and any additional equipment to control emissions. Mass emission factors for CO_2, SO_2, and nitric oxide (NO) are calculated based on input data, such as the chemical composition of coal used in power plants and the actual air used during combustion.

Boiler technology is used in domestic power plants, where a liquid bed boiler can maintain a suitable desulphurization furnace temperature, but a coal dust boiler makes it difficult to maintain high desulphurization efficiency due to gas temperature control the retention temperature suitable for the reaction is limited (short). In Figure 1a a schematic diagram of the exhaust gas system of Kosovo A boiler will be presented, while Figure 1b) shows the boiler for the dust measuring position. Both inlet and outlet positions are located slightly in front of/behind a bending channel.

Table 1. Kosovo lignite coal analysis results

Parameter	Original coal	Air dried	Test methods
Humidity %	47.68	12.34	ASTM D 3302
Ash %	14.61	24.48	ASTM D 3174
Total sulfur %	0.45	0.75	ASTM D 4239
Organic sulfur	0.32	0.68	ISO 157: 1999
Caloric value kcal/kg	2668	4389	ISO 1928: 2009

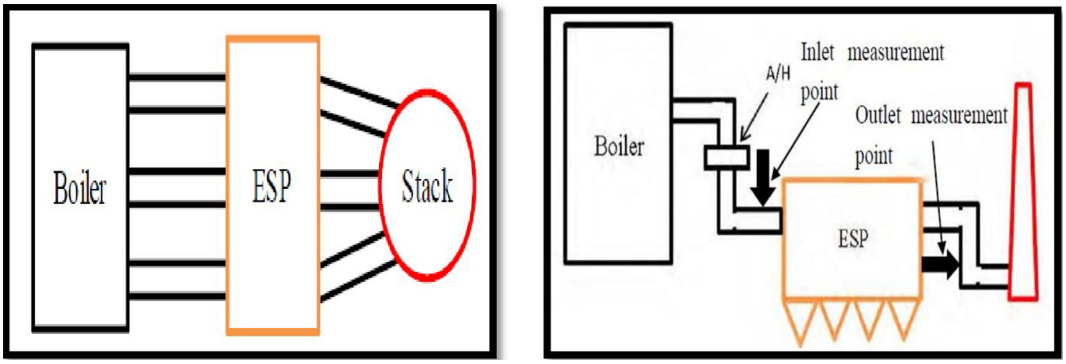

Figure 1. Schematic diagram of exhaust gas system of Kosovo A boiler and vertical cross-sectional image of measurement points (Japan International Cooperation Agency (JICA), 2016)

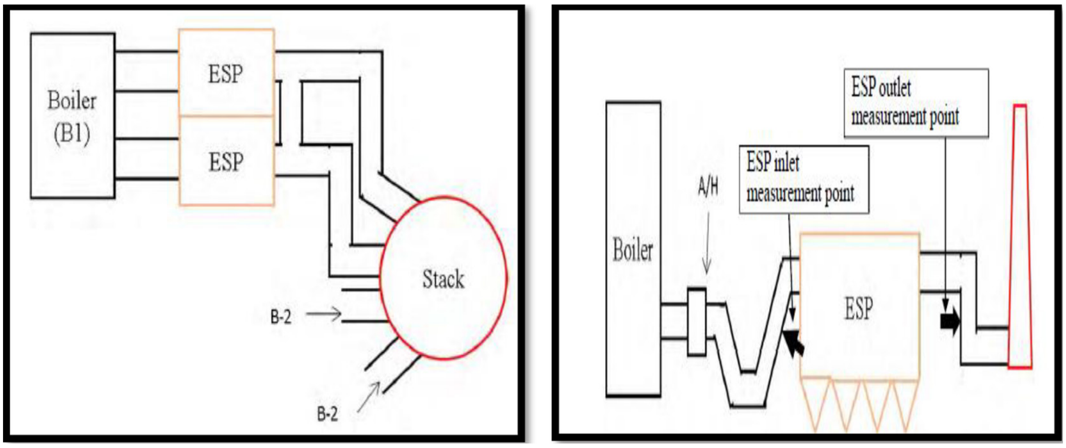

Figure 2. Schematic diagram of exhaust gas system of Kosovo B boiler and vertical cross-sectional image of measurement point (Japan International Cooperation Agency (JICA), 2016)

TPP Kosova B differs from TPP Kosova A because it has 2 boilers, B-1 and B-2, and each boiler has 2 ESP, as shown in the schematic diagram in the Figure 2a). Moreover, the exhaust gas from each boiler merges into one stack, and that stack discharges all the exhaust gas, whereas Figure 2b) presents the vertical view with a cross-section in ESP, including new measuring holes, including measuring points.

The amount of SO_X generation mainly depends on the sulfur (S) content in the coal that is formed during combustion. If it is possible to provide coal that contains less sulfur, this is an effective way to reduce SO_X generation. The high batch also has a long history of use to induce the propagation of SO_X into the atmosphere to reduce the SO_X reduction density.

There are two methods for removing SO_X from lignite, the first is by injecting limestone into the kiln, which results in the formation of gypsum ($CaSO_4$) in the kiln; this is called "furnace desulfurization". The second method is to use the chemical reaction between the $CaCO_3$ and SO_X slurry, which proceeds to a wet-type desulfurization system (FGD system) installed between the boiler and the stack. In desulfurization in the furnace, the chemical reaction between CaO (produced by $CaCO_3$ in the limestone injection furnace) and SO_X continues in the furnace at a gas temperature of about 850°C, and SO_X is captured as $CaSO_4$.

In this system, higher desulphurization requires an appropriate reaction gas temperature and a large amount of limestone injection, which is required for the SO_X reaction. In the implementation of this system, attention should be paid to the design of the ash treatment system, as the amount of dust in the flue gases will increase from the $CaSO_4$ generated in the process, along with the remaining unreacted CaO.

RESULTS AND DISCUSSION

Given that the part of sulfur in lignite is combustible sulfur. Lignite burns in an enclosed space in the boiler at 815 °C, this is a suitable temperature for the reaction to form $CaSO_4$ when SO_2 exists in the presence of CaO. SO_X can react with floating CaO in the furnace. As a result, the emitted SO_2 content in the flue gas may be lower than the SO_X formed by the combustion of combustible S in lignite when measured in the laboratory.

Calculation of SO_2 emissions per hour can be based on concentration measurements as shown in equation 1 (U.S. National Pollutant Inventory Emission Estimation Technique Manual, 1999):

$$E_i = \frac{C \cdot MW \cdot Q_{st} \cdot 3600}{\left[22.4 \cdot \left(\frac{T+273}{273}\right) \cdot 10^6\right]} \quad (1)$$

where: E_i – emissions of pollutant i, kg/hr, C – pollutant concentration, ppmv, d, MW – molecular weight of the pollutant, kg/kg-mole, Q_{st} – stack gas volumetric flow rate at actual conditions, m^3/s, 3600 – conversion factor, s/hr, T – temperature of the gas sample, ℃, 10^6 – conversion factor, ppm·kg/kg, 22.4 – volume occupied by one mole of gas at standard temperature and pressure (0 °C and 101.3 kPa), m^3/kg-mol.

The data obtained from the measurements of the important parameters of coal quality (moisture, general sulfur, organic sulfur, and high thermal effect) about the emission of SO_2 after the burning of coal throughout the year 2023 in the Kosovo Thermal Power Plant are presented in Table 2 and Figure 3.

These data have shown that some parameters can be related and that their behavior depends a lot on the quality of the lignite used for energy production throughout the analyzed year. Figure 2 shows reports on coal quality indicators and SO_2 emissions as a coal combustion product in Kosovo's power plants. From the samples analyzed during 2023, differences were observed between the behavior of the parameters that were also the subjects of this paper, the SO_2 emission ratio will be lower in the case where the thermal effect of lignite is high as shown in the Figure 3.

As shown in Figure 4, there is a very different ratio between SO_2 emission which is low when humidity is low and SO_2 emission increases with increasing humidity. We also observed the relationship between SO_2 emission and the presence of sulfur in lignite, total sulfur, and organic sulfur when they were present in low amounts in coal and SO_2 emission was low and the opposite when their

Table 2. The relationship between coal quality parameters and SO_2 emission after coal combustion

Year 2023	Moisture, (%)	Total sulfur, (%)	Organic sulfur, (%)	High thermal effect, (KJ/Kg)	Ppm	E_{SO2} (kg/hr)
Jan	49.38	1.58	0.86	18232	522.4	824.5
Feb	50.59	1.65	0.93	18135	572.7	1104.1
Mar	48.32	1.28	0.61	19289	500.1	874.9
Apr	48.14	1.48	0.64	19305	320.9	629.8
May	48.89	1.53	0.83	19251	362.4	712.9
Jun	48.75	1.51	0.71	19321	366.8	643.6
Jul	48.15	1.44	0.62	19142	375.2	671.4
Aug	49.17	1.47	0.76	18954	343.8	622.5
Sep	49.54	1.52	0.89	18845	353.9	701.1
Oct	49.62	1.59	0.82	18745	513.4	828.9
Nov	49.86	1.61	0.87	18103	455.9	823.9
Dec	50.18	1.33	0.92	18146	196.4	891.4

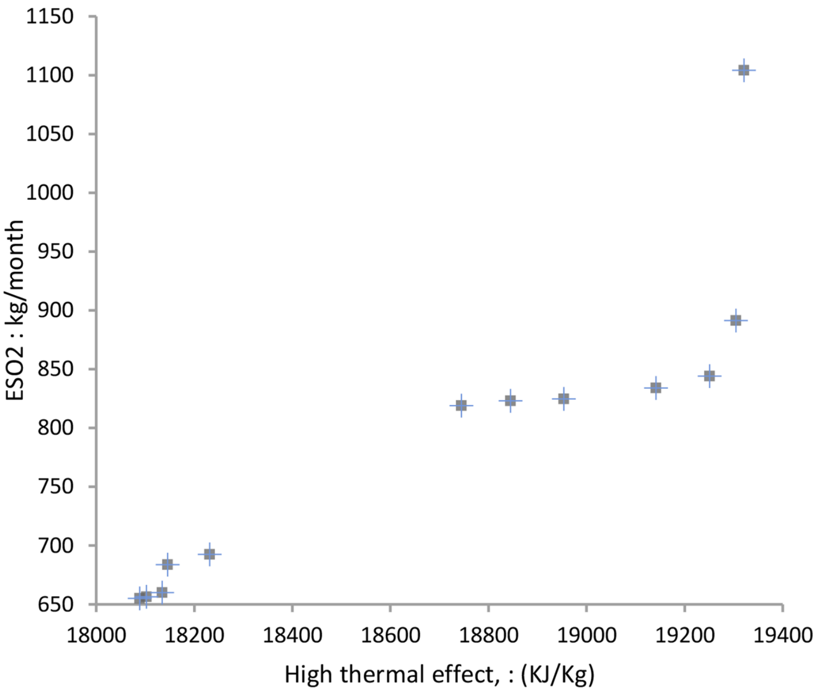

Figure 3. Relationship between SO_2 emission and thermal effect of lignite

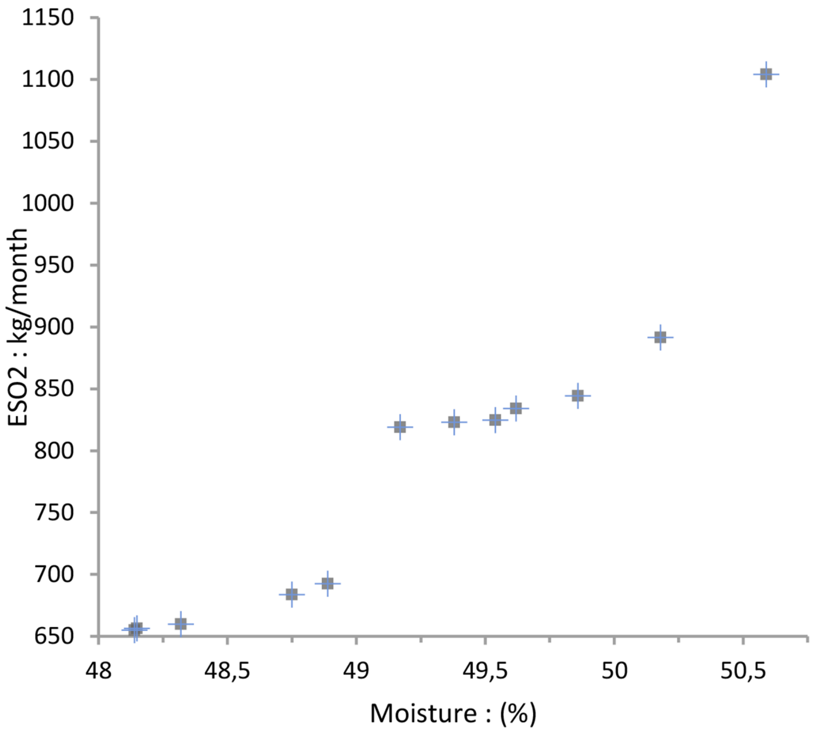

Figure 4. Relationship between SO_2 emission and humidity of lignite

amount was high and emission of SO_2 was high (all these ratios are also shown in Figure 5 and 6).

The correlation matrix, along with its significance, between the lignite parameters was determined in Table 7 in terms of the Pearson correlation coefficient and SO_2 emissions as a coal combustion product in Kosovo's power plants. The significant correlations for the year 2023 between the analyzed parameters represent an expected correlation for all analyzed samples. The mutual correlation with a value of 0.941 between Humidity and the emission of SO_2 as a lignite combustion product

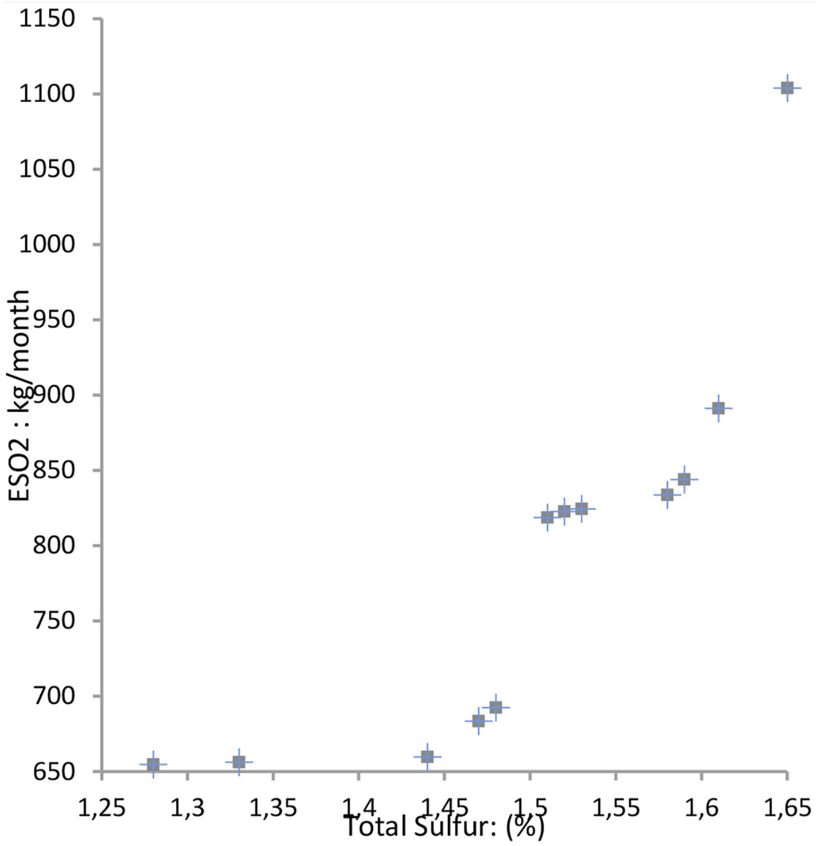

Figure 5. Relationship between SO_2 emission and total sulfur of lignite

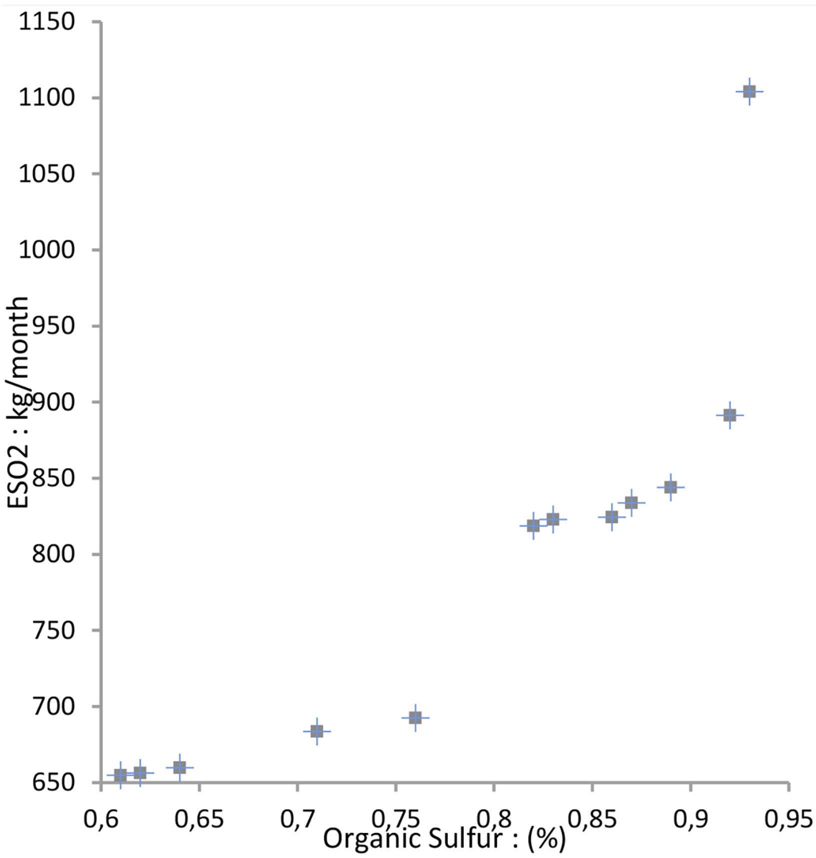

Figure 6. Relationship between SO_2 emission and organic sulfur of lignite

Table 3. Pearson correlation coefficient between coal quality parameters and SO_2 emission

Pearson's r	Moisture	Total sulfur	Organic sulfur	High thermal effect	ESO_2
Moisture	-	0.945	0.974	-0.937	0.941
General sulfur	0.945	-	0.948	-0.896	0.842
Organic sulfur	0.974	0.948	-	-0.919	0.875
High thermal effect	-0.937	-0.896	-0.919	-	-0.848
ESO_2	0.941	0.842	0.875	-0.848	-

in Kosovo's power plants is a positive coefficient, such a relationship is explained as a very strong positive relationship, which means that humidity in itself constitutes an amount of SO_2 which then transferred to emission. The value of the Pearson correlation coefficient of 0.842 between the content of general sulfur and the emission of SO_2 in lignite reflects a strong positive relationship, which means that with the increase of general sulfur, it is expected that the emission of SO_2 will also increase. Analyzing the Pearson correlation coefficient with a value of 0.875 between Organic Sulfur and the emission of SO_2 in lignite shows that the main part of SO_2 that is emitted originates from organic sulfur and the relationship is strongly positive which means that with the increase of organic sulfur, it is expected that the emission of SO_2 also increases and requires pollution management and improvement of lignite combustion technology.

In our paper, we also analyzed the Pearson correlation coefficient between high thermal value and SO_2 emission in lignite, the value of which is -0.848, which shows a very strong negative relationship between high thermal value and SO_2 emission in lignite. This relationship means that increasing the high calorific value of lignite leads to a decrease in SO_2 emissions, which can be important for the optimization of energy sources and the reduction of air pollution.

CONCLUSIONS

Improved emissions inventories that include one-year real-time monitoring and historical data can increase the accuracy of emission estimates of SO_2, the constituents that are active components during the coal combustion process and that are highly reactive and quite harmful for the ecosystem. This research helps track progress and identify trends in organic sulfur emissions from lignite power plants. The use of advanced technologies such as remote sensors used to determine SO_2 emission factors are widely accepted tools for evaluating the emissions of these gases.

Specific assessments of organic sulfur compounds in overall SO_2 emissions are essential for assessing their environmental impact, especially in terms of acid rain formation, soil and water acidification. Emission factors for criteria pollutants such as SO_2 are widely accepted tools for estimating the emissions of these gases. Based on one year's analyses, sulfur compounds contained in coal have a high reactivity and are an active part of the lignite powder combustion process.

The comparison of the level of SO_2 compounds between the two power plants Kosovo A and B is obvious, from the obtained results it is clear that in Kosovo B this level is much higher due to the lack of filters that reduce these compounds dangerously. The ratios of moisture, general sulfur, and organic sulfur with SO_2 emission viewed from the Parson correlation aspect presented a strong positive relationship; more humidity leads to more SO_2 emissions, while the high thermal value and SO_2 emission ratio: show a very strong negative relationship; higher thermal value leads to less SO_2 emissions.

The assessment of organic SO_2 emissions from domestic lignite power plants recommends the use of advanced measurement techniques, comprehensive emissions inventories, sophisticated data analysis and modeling, and the application of these assessments in regulatory, environmental and health contexts. These assessments lead to more accurate, reliable and actionable data, supporting better decision-making and policy development.

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