Aerosol and Air Quality Research

ORIGINAL RESEARCH
https://doi.org/10.4209/aaqr.210399

Impact of COVID-19 Case Numbers on the Emission of Pollutants from a Medical Waste Incineration Plant

Special Issue:
Air Quality in a Changed World: Regional, Ambient, and Indoor Air Concentrations from the COVID to Post-COVID Era (V)

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ABSTRACT

This article examines the correlation between the amount of pollutants emitted from medical waste incinerator plant and the number of COVID-19 infections, based on the example of Podlaskie Voivodeship in Poland. This paper deals with the issues of medical waste management during the COVID-19 pandemic. Thermal processing is characterised as a method of medical waste utilisation. The technological sequence of the medical waste incineration installation and the integrated exhaust gas cleaning system are discussed. The results of studies on the emission of pollutants into the atmosphere during combustion are compared with the number of COVID-19 cases in the same voivodeship to investigate how the coronavirus pandemic affects the amount of medical waste generated, thus the amount of pollutants emitted into the atmosphere. The Pearson's linear correlation coefficient and the Student's t-test are used to verify the results. The analysis results show a statistically significant, moderate positive correlation between the amount of covid waste and the number of COVID-19 cases (0.5140). In turn, there is also a statistically significant moderate correlation between the number of COVID-19 cases and emissions of SO_2 ($r = 0.6256$, $p = 0.010$), NO_x (0.5019, $p = 0.048$), and HCl (0.5130, $p = 0.042$). This correlation finding highlights additional costs to the environment and public health as the number of COVID-19 cases increase, which can be taken into account for pandemic planning by governments in the future.

Keywords: Air pollution, Emission, Medical waste, Thermal waste treatment, COVID-19

OPEN ACCESS

Received: December 28, 2021
Revised: March 18, 2022
Accepted: March 25, 2023

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Publisher:
Taiwan Association for Aerosol Research
ISSN: 1680-8584 print
ISSN: 2071-1409 online

1 INTRODUCTION

The COVID-19 pandemic causes problems in many areas of society: in the national economy, industry and transport, but above all in healthcare. The pandemic poses a challenge in providing medical care for a large number of people and protecting against the spread of the coronavirus. The high number of infections and the need to minimise the risk of disease results in the increased use of personal protective equipment (PPE), such as face masks, aprons, gloves, goggles and other single-use medical-care equipment. PPE is an essential tool that can protect people from COVID-19 infection and minimize the health and economic impact of the pandemic on a global scale (Liu and Schauer, 2021). PPE has become common among medical services and the domestic population (Valizadech *et al.*, 2021). Mandatory face-covering introduced by many governments results in the use of face masks on an unprecedented scale (Park *et al.*, 2021). Increased use of PPE is also associated with the performance of COVID-19 tests and a large number of hospital admissions. The amount of medical waste produced when people with COVID-19 are hospitalised has been found to be up to 2–4 times higher than those with other diseases (Wang *et al.*, 2021). The scale of this phenomenon is best illustrated by an increase in PPE production of up to 40% compared to the pre-pandemic period (Thind *et al.*, 2021).

Increased use of personal protective equipment results in an exponential increase in medical waste (Zhao *et al.*, 2021). In Wuhan, the waste production from the yellow category of biomedical waste increased sixfold during the pandemic's peak (Thind *et al.*, 2021). In Hubei Province, waste production increased four times (Joint Prevention and Control Mechanism of the State Council, 2020). Due to the high risk of infection and high survivability of the coronavirus, most of the waste generated in healthcare facilities must be treated as medical waste (Yang *et al.*, 2021). Moreover, this is not only PPE waste but also other waste generated from the observation, isolation, testing and healing people with COVID-19, like hand sanitiser, disinfectant and drug containers, paper towels, swabs, syringes, needles, blades, bandages, tapes (Purnomo *et al.*, 2021). The characteristic of medical waste is different compared to the waste generated in the pre-pandemic period. COVID-19 waste belongs to a specific plastics group (Thind *et al.*, 2021) and has a lower density than pre-pandemic medical waste (Purnomo *et al.*, 2021). That affects the waste disposal process and may also impact emissions from incineration (e.g., may increase emissions of alkali metals and HCl) (Lan *et al.*, 2021). Moreover, the fact that covid waste belongs to the plastics group makes it a potential source of microplastics. Incorrect handling of this type of waste results in the release of microplastics into the environment (Liu and Schauer, 2021). The significant increase in medical waste poses a challenge to the waste management system (Wang *et al.*, 2021). Hazardous waste must be stored and urgently disposed of to prevent the pandemic's spread (Mei *et al.*, 2021) and control the source of infection (Peng *et al.*, 2020). Proper management of medical waste is understood as controlling the entire process, which consists of collecting, transporting, and final processing (Chen *et al.*, 2021). Medical waste disposal is a complex process including economic, technical, environmental and social aspects (Liu *et al.*, 2015). The COVID-19 pandemic has necessitated the development of effective methods of handling medical waste in order to quickly dispose of large amounts of waste at low costs and minimal safety risk. Many authors raise this issue (Mei *et al.*, 2021; Ma *et al.*, 2020; Chen *et al.*, 2021; Valizadech *et al.*, 2021; Fraifeld *et al.*, 2021; Nowakowski and Pamuła, 2020; Zamparas *et al.*, 2019; Aung *et al.*, 2019; Omoleke *et al.*, 2021; Kenny and Priyadarshini, 2021).

An example is the emergency reverse logistics siting model for medical waste presented by Mei *et al.* (2021) or the guidelines for emergency handling of a large amount of medical waste prepared by Mei *et al.* (2021). Chen *et al.* (2021) analyse medical waste management after the outbreak of the COVID-19 pandemic. Changes in waste management in Wuhan city are presented based on waste generation, storage, transportation and disposal data. The results show that despite a fivefold increase medical waste at the peak, all was disposed of within 24 hours of generation. The authors indicate that quick and effective disposal is a crucial element in the fight against pandemics of medical waste (Chen *et al.*, 2021). Similar conclusions are made by Valizadech *et al.* (2021), who additionally highlight the costs of waste incineration. Based on a hybrid mathematical model, it is concluded that appropriate waste management could contribute to the production of energy from waste and thus reduce the cost of medical waste disposal.

Fraifeld *et al.* (2021) highlight the importance of medical waste segregation and its impact on financial savings and reduced environmental pollution.

Proper waste segregation is also the subject of research by Nowakowski and Pamuła (2020), that propose an image recognition system for waste identification and classification. Zamparas *et al.* (2019), on the other hand, highlight the integrated management of hazardous waste in terms of achieving environmental goals and effective energy consumption. Aung *et al.* (2019) propose an assessment framework for medical waste management, based on World Health Organization (WHO) guidelines, to safely manage waste from healthcare activities.

Omoleke *et al.* (2021) express dissatisfaction with the methods of medical waste disposal in developing countries. The preferred methods are incineration and burial of waste on hospital premises, due to inadequate funding for waste management. Proper handling of medical waste and the use of appropriate disposal methods require specific financial resources. Kenny and Priyadarshini (2021) provide a detailed review of healthcare waste disposal methods, i.e., incineration, landfilling and chemical treatments. The authors analyse the efficiency of these methods and their negative impact on the environment and human health. Like Omoleke *et al.* (2021), they point out significant differences in waste disposal methods in developing and developed countries.

The basic and most commonly used medical waste disposal method is thermal treatment (Liu *et al.*, 2015). Thermal conversion technologies for medical waste disposal include incineration (McKay, 2002), carbonisation/torrefaction (Świechowski *et al.*, 2021), pyrolysis (Zroychikov *et al.*, 2018) and gasification (Kim *et al.*, 2011). The choice of method depends on the composition of the waste. Combustion cannot be used for nitrile gloves, goggles or hand sanitiser containers but can be used for face masks. Pyrolysis and gasification are lowly feasible for latex and nitrile gloves but are highly feasible for masks (Purnamo *et al.*, 2021). New methods are developed to improve the efficiency of waste disposal processes, e.g., by using additives to COVID-19 waste, like the addition of food waste during co-pyrolisis of face masks (Park *et al.*, 2021).

A highly feasible method for most COVID-19 waste is incineration (Purnamo *et al.*, 2021). This method effectively combats microorganisms and significantly reduces the volume and mass of the waste (Windfeld and Brooks, 2015). The disadvantages of waste incineration are the emission of many toxic substances (Chen *et al.*, 2012) and the formation of persistent organic pollutants POPs (Li *et al.*, 2020). Therefore, in medical waste incineration plants, it is necessary to use highly-efficient filtering devices and continuously monitor exhaust gas quality (Totczyk, 2011). The cost of air pollution treatment can account for 50% of the total incineration operating costs (Purnamo *et al.*, 2021).

The pollutants emitted into the air during medical waste treatment are mainly dust, sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x), hydrogen chloride (HCl), hydrogen fluoride (HF), total organic carbon (TOC) and carbon dioxide (CO_2). The amount of pollutants emitted depends on the amount of waste incinerated and the type of waste (Totczyk, 2011).

According to WHO (WHO, 2022), 5,415,014 COVID-19 cases were confirmed in Poland between 3 January 2020 and 14 February 2022, which accounts for 14.1% of the Polish population (GUS, 2022) and 3.3% of all cases in Europe. The fifth wave of the pandemic is now gaining momentum, increasing the number of people hospitalised, thus affecting the use of personal protective equipment and an increase in the amount of hazardous medical waste. Therefore, the topic of medical waste during the COVID-19 epidemic is still relevant.

In Poland, the basic legal act regulating the handling of medical waste is the Polish Waste Act of 14 December 2012, which defines this type of waste as "arising in connection with the provision of health services and research and scientific experiments in the field of medicine". According to the Polish Waste Act (2012), it is forbidden to dispose of infectious medical waste outside the voivodeship where it was produced. Thus, waste generated in a given voivodeship must be disposed of in a local medical waste incineration plant, following the proximity principle. An exception is when there is no installation for the disposal of this waste in a given voivodeship or when the existing installations have no free processing capacity - then it is allowed to dispose of medical waste in another voivodeship (Polish Waste Act, 2012).

The issue of the impact of pandemic COVID-19 on the amount of medical waste is addressed in some studies. It is mainly concerned with determining the correlation between waste volumes and COVID-19 cases rather than the correlation between COVID-19 cases and emitted pollutants. An example of such a study is presented by Maalouf and Maalouf (2021). They analyse the relationship between increased COVID-19 cases and covid waste (infectious waste associated with COVID-19) in Lebanon in February 2020 and October 2020. The above relationship was examined monthly, and the correlation coefficient was $R^2 = 0.9704$. Thus, increasing medical waste generation is strongly associated with COVID-19 incidence. The authors note the correlation between COVID-19 cases and some contaminants from medical waste incineration. A linear relationship between the number of infected people and the amount of waste is indicated by ADB (2020). The proposed formula calculates the amount of waste in kg d^{-1} by multiplying the number of cases by a factor of 3.4. Mihai (2020) indicates a linear relationship between the number of people hospitalised with COVID-19 and the amount of waste generated.

This article describes the pollutants emitted during the thermal treatment of medical waste in an incineration plant operating in Podlaskie Voivodeship, located in north-eastern Poland. The analysis covers the period from March 2020 to June 2021 during the COVID-19 epidemic. The technological line of medical waste incineration plants is discussed, together with the exhaust gas cleaning installation. The study results of pollutant emissions to the atmosphere are presented, comparing them with the number of COVID-19 cases in the same province to investigate how the coronavirus pandemic affects the amount of pollutants emitted to the atmosphere during medical waste incineration.

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2 METHODS

Medical waste should be transported for disposal within 30 days of its generation (Dziennik Ustaw Rzeczypospolitej Polskiej, 2017). The waste that is disposed of in the studied incineration plant comes from the entire Podlaskie Voivodeship, under the proximity principle, which requires thermal treatment of medical waste in the voivodeship where it was produced. The medical waste management process is presented in Fig. 1.

After the medical waste is sent to the incineration plant, the final process is s thermal transformation, i.e., disposal. During thermal transformation, pollutants are produced, which are minimised by the exhaust gas cleaning system. The source of the formation of polluting substances is the pyrolysis chamber, in which the charge gasification process takes place at the temperature of 650°C. In the thermoreactor the gasified substances are burnt at the temperature of 1200°C. Pollutants are introduced into the air by an emitter with a height of 8.0 m above ground level, an external diameter of the outlet 0.3 m and a gas flow rate of 2281 $m^3 h^{-1}$. The medical waste incinerator is equipped with an exhaust gas cleaning system (wet and dry technology). The maximum efficiency of pollutant removal is 99.6%. The exhaust gas treatment system consists of the following elements: cooling column, installation of a dry filter, sorbalite tank, exhaust pipes, exhaust gas cooling (quench), exhaust gas scrubber, fan speed controller, NaOH dosing tank, cleaned exhaust gas emitter.

The scheme of the analysed installation for thermal processing of medical waste is presented in the Fig. 2.

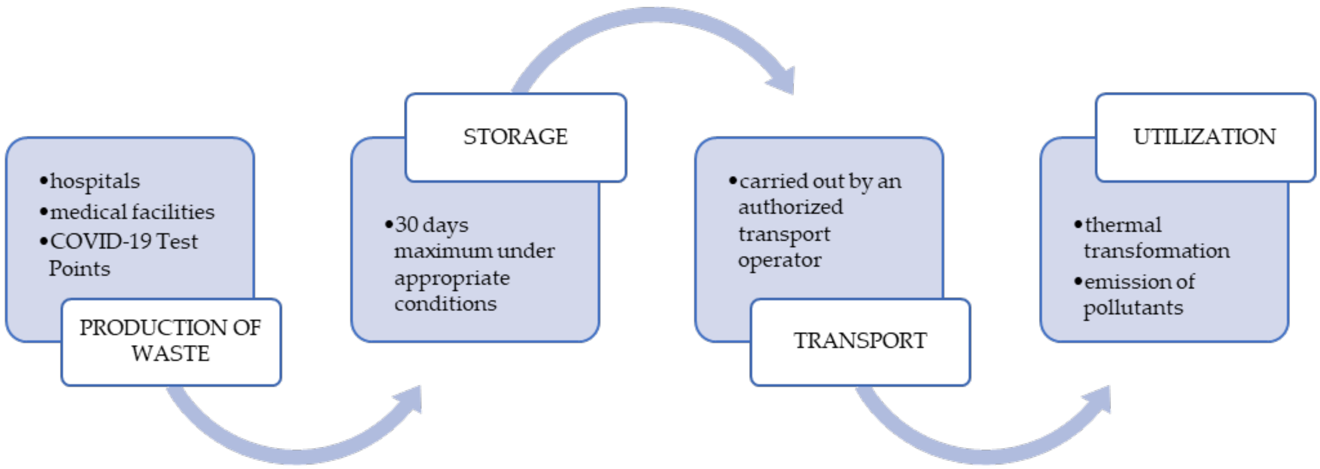

Fig. 1. Medical waste management - from generation to disposal in a medical waste incineration plant.

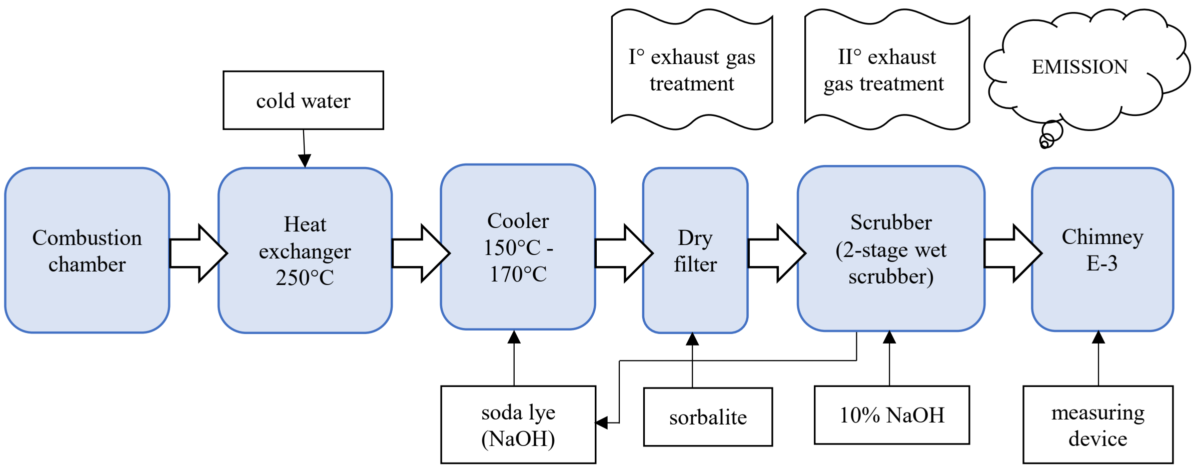

Fig. 2. Scheme of the installation of thermal waste conversion with the exhaust gas treatment system.

The exhaust gases with a temperature of approx. 250°C leave the heat exchanger and are directed to the cooler, to cool them down. The heat given off is used to evaporate the injected water and the exhausted NaOH solution. Control of the water and soda lye injection is automatic. The injected soda lye is the wastewater from the second stage of purification, i.e., a counter-current scrubber. In order to stabilize the temperature in the cooler, cold water is supplied from the hydro-duct. In the cooler, the gases reach a temperature of approx. 150–170°C. The refrigerant used for cooling the exhaust gases (a partially exhausted NaOH solution) has a slightly alkaline pH = 7.7–7.9. The acid exhaust gas is pre-neutralised in the cooler. The cooled gas stream from the cooler is piped to the first stage of purification, i.e., the dry filter. As the exhaust gas enters the dry filter, sorbalite (a mixture of activated carbon and hydrated lime) is automatically dosed through a dosing system.

Sorbalite neutralises the waste acid gases, particularly SO_2, and absorbs dioxins, furans and heavy metals. The dry filter with sorbalite dosing system is the first stage of exhaust gas purification. The gas stream flowing into the filter contains spent sorbalite, fly ash, dust particles precipitated after evaporating the liquid in the cooler and impurities absorbed by activated carbon. Contaminants in the exhaust gas - aerosol particles $< 0.1\ \mu m$ in size, are precipitated in the filter and discharged as secondary waste to the container. The filter construction ensures automatic, selfcleaning of the filtering cloth (bags) by pulsating blows of compressed air, without the necessity of interrupting the operation of the installation. The next stage of exhaust gas treatment is absorption in the so-called two-stage wet scrubber. Further neutralisation of the gaseous acid substance, mainly HF and HCl, occurs in this device. For this purpose, a 10% sodium base solution of NaOH is used as the active substance, dosed counter-currently into the scrubber from a storage tank using automatically controlled pumps. The amount of dosed NaOH solution depends on the pH of the withdrawn solution. The scrubber wastewater containing precipitated and dissolved pollutants and some free reagent is kept in a closed circuit. Part of this wastewater is directed to cool the exhaust gases in the cooler. The cleaned exhaust gases are directed to the atmosphere by the emitter through the exhaust fan.

Monitoring of the process of emission of pollutants to the atmosphere is carried out by means of an automatic, electronic measurement system that continuously reads and records the measurement results. There are two M64x4 measuring nozzles in the gas emitter, meeting the legal requirements and enabling the measurement of emissions. The medical waste incineration plant is equipped with the MIKROS v.10 continuous exhaust gas monitoring system from MikroB S.A. The main elements of the measurement structure are measurement devices (analysers, meters), an emission computer for data processing and transmission and a software package for remote control and emissions monitoring. The continuous emission monitoring system detects dust and gaseous pollutants such as dust, SO_2, CO, NO_x, HCl, HF, TOC, and CO_2 (MikroB, 2021).

The starting point for analysing air emissions data is to examine the correlation between the number of COVID-19 cases and the amount of covid waste over the period March 2020–June 2021. Then, daily data of emitted pollutants are summed up. The obtained monthly amounts of emitted pollutants in kilograms are compared with the number of COVID-19 cases in the voivodeship with the analysed waste incineration plant.

The data are compiled in tabular form and then statistically analysed in MS Excel.

STAGE I – Statistical Analysis - Calculation of the Correlation Coefficient

The first step is to calculate the Pearson's linear correlation coefficient in order to analyse two problems: correlation between the amount of medical waste and the number of COVID-19 cases, and correlation between the number of pollutants emitted into the air from medical waste incinerator plant and the number of COVID-19 cases.

The linear correlation coefficient r_{XY} is calculated based on the covariance value between the analysed features and the value of their variance, using formulas presented by Wijayatunga (2016) and Sulewska (2011).

STAGE II – Statistical Verification - Testing the Significance of the Pearson Linear Correlation

The second stage examines the significance of the correlation coefficient r, which is an

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assessment of the correlation coefficient q in the general population and therefore is burdened with some error. We test the significance of the correlation coefficient using the Student's t-test (Teleszewski, 2018, 2020). The hypothesis about the statistical significance of the correlation coefficient p is verified using the t-statistic. The t* value is determined using the Student's t-tables, while the t value is calculated from the linear correlation coefficient r_{XY} and the sample size. If $t > t^*$, then the null hypothesis H_0 should be rejected in favour of the alternative hypothesis H_A. This means that the correlation coefficient p is statistically significant, and therefore the correlation of the studied variables is statistically significant.

3 RESULTS AND DISCUSSION

The Table 1 presents monthly total emission of particular pollutants into the air from medical waste incineration plant, the amount of covid waste, and the number of COVID-19 cases in the Podlaskie Voivodeship, where the medical waste incineration plant operates. The following pollutants are produced in the incineration plant: dust, SO_2, CO, NO_x, HCl, HF, TOC, CO_2.

The number of cases in the analysed period varied from 35 to 17,500 per month. Two months with the highest number of cases can be chosen, i.e., November 2020 and March 2021, which is related to the culmination of the Poland's 2nd and 3rd COVID-19 wave. The structure of pollutant emissions from the medical waste treatment process also varies depending on the number of cases. The structure of emitted pollutants for the month with the lowest (Fig. 3) and highest (Fig. 4) number of COVID-19 cases in the analysed period is presented below.

CO_2 has the largest share in the emission of pollutants in March 2020 - as much as 40% of all pollutants. Next are CO with a share of 26% and NO_x with a share of 25% in the total mass of emitted pollutants.

The structure of pollutant emissions is completely different in November 2020, when the highest number of COVID-19 cases was recorded during the analysed period. NO_x have the largest share of pollutant emissions at the level of 48%, which is almost twice as much as in March 2020. In second place is CO with 19%, which is twice smaller value compared to March 2020 emissions. In third place is CO_2 with a share of 16%. The more than 2-fold increase in SO_2 emissions, from 5% in March 2020 to 12% in November 2020, also seems worrying HCl has a small percentage share of only 3%, but this is as much as a 3-fold increase in emissions compared to March 2020, which may be alarming due to its toxic effects on the environment.

Table 1. The monthly total emission of selected pollutants from incineration of medical waste, the amount of covid waste and the number of COVID-19 cases in Podlaskie Voivodeship.

Month	Dust (kg)	SO_2 (kg)	CO (kg)	NO_x (kg)	HCl (kg)	HF (kg)	TOC (kg)	CO_2 (kg)	Amount of disposed waste (mg)	Cases of COVID-19
March 2020	0.435	5.056	25.624	24.012	1.185	0.044	2.933	38.817	1.12	35
April 2020	0.211	0.207	19.040	15.379	0.466	0.019	3.366	16.451	13.99	281
May 2020	0.344	0.109	29.667	28.693	0.284	0.024	5.626	22.488	7.35	80
June 2020	0.280	0.048	25.469	29.049	0.470	0.033	4.702	20.059	8.36	393
July 2020	0.252	7.926	18.517	26.457	1.455	0.020	1.580	18.899	10.06	136
August 2020	0.025	3.255	10.256	15.255	1.458	0.021	1.889	25.487	4.48	324
September 2020	0.334	9.481	23.225	28.405	3.393	0.037	2.006	17.517	7.46	755
October 2020	0.385	10.084	23.981	43.723	3.456	0.057	2.177	18.831	14.65	6671
November 2020	0.379	12.256	19.353	47.452	2.596	0.059	1.909	15.765	13.44	17500
December 2020	0.669	7.257	13.951	34.654	2.330	0.070	1.124	13.987	10.90	7875
January 2021	1.019	3.725	7.422	13.781	1.614	0.011	0.708	8.329	6.12	6761
February 2021	0.165	4.551	9.448	16.902	1.544	0.010	0.860	10.233	12.28	6580
March 2021	0.235	8.857	13.252	25.343	2.040	0.012	1.373	14.526	15.10	12319
April 2021	0.212	7.913	13.142	26.190	2.463	0.028	1.351	14.719	12.22	8197
May 2021	0.148	6.078	6.776	22.212	0.976	0.023	0.959	10.701	9.61	1719
June 2021	0.145	6.268	6.741	24.088	1.715	0.028	1.003	11.505	13.29	211

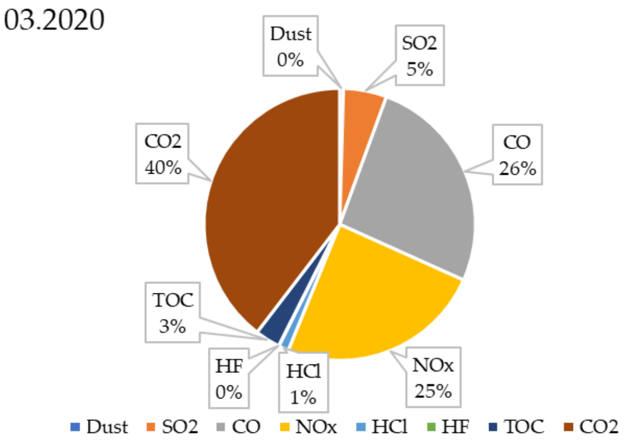

Fig. 3. Structure of pollutant emissions from medical waste incineration plants in March 2020 with a minimum number of COVID-19 cases.

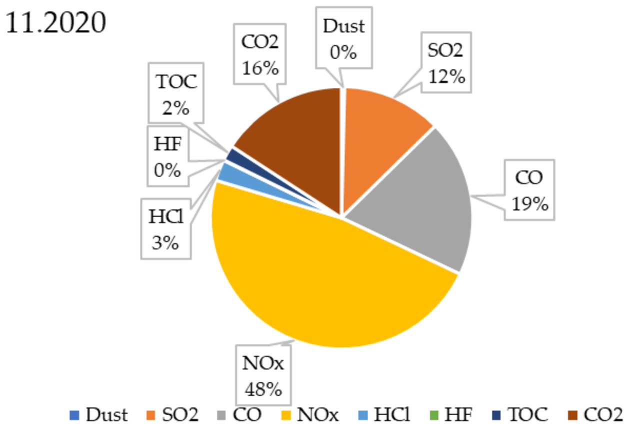

Fig. 4. The structure of pollutant emissions from medical waste incineration plants in November 2020 with the maximum number of COVID-19 cases.

Totczyk (2011) shows a similarity to the above study, where she analyses the pollutants emitted from medical waste incineration plants before the COVID-19 pandemic. NO_x have the largest share in the emission of pollutants into the air, where the average daily concentration was 134.56 mg m^{-3}. Other significant pollutants are CO - 27.26 mg m^{-3} and SO_2 - 23.28 mg m^{-3}. In turn, Dan *et al.* (2021) compare the number of pollutants emitted from municipal waste incinerators located on the plateau and in the plains. In municipal waste incineration plants located on plains (as the incinerator in this article), NO_x, between 86.00 and 240.00 mg m^{-3}, have the highest share in emissions, followed by CO in the range 13.00–78.00 mg m^{-3} and SO_2 in the range of 7.00–74.00 mg m^{-3}. Głodek (2011) compares the number of emissions from waste incineration for incineration, cementation and uncontrolled incineration. The highest emission factor is characteristic for NO_x - 1.6 g kg^{-1}, then HCl - 0.058 g kg^{-1} and SO_x - 0.042 g kg^{-1}.

The data presented on the amount of waste, the amount of emitted pollutants and the number of COVID-19 cases are analysed statistically. First, the correlation between the number of COVID-19 cases and the amount of treated covid waste is examined to assess whether and what impact the COVID-19 pandemic has on the amount of waste generated. Then the correlation between the number of cases and the emission of pollutants generated during the incineration of medical waste is analysed.

STAGE I – Statistical Analysis - Calculation of the Pearson's Linear Correlation Coefficient

First, a linear correlation coefficient between the amount of covid waste and the number of

Table 2. Pearson's correlation coefficient and significance values for monthly number of COVID cases vs. amount of emitted compound.

	Dust	SO_2	CO	NO_x	HCl	HF	TOC	CO_2
r_{xy}	0.2665	0.6256	–0.1905	0.5019	0.5130	0.2952	–0.3905	–0.3772
p-value	0.318	0.010	0.480	0.048	0.042	0.267	0.135	0.150

COVID-19 cases is calculated and equals $r_{x,y} = 0.514$. The result is in the range $0.4 < | r_{XY} | < 0.7$, therefore it is a moderate correlation relationship.

Then, Pearson's linear correlation coefficients are calculated for each pollution pair - the number of COVID-19 cases (Table 2).

STAGE II – Statistical Verification - Testing the Significance of the Pearson Linear Correlation

The significance of the Pearson linear correlation between the amount of medical waste and the number of COVID-19 cases, and the number of COVID-19 cases and the amount of emitted pollutants, is tested using the Student's t-test. The t-value for the correlation between the amount of COVID waste sent to the incinerator and the number of COVID-19 cases is t = 2.2427, which is greater than the t-critical value ($t^*_{0.05,\ 16-2} = 2.1448$), yielding a p-value of 0.042. In sum, the value of the Pearson correlation coefficient is statistically significant for the variable – the amount of covid disposal waste. It means that the number of COVID-19 cases has a moderate impact on the amount of covid-related waste generated.

Student's t-test values for SO_2 (t = 3.0009), NO_x (t = 2.1712), and HCl (t = 2.2363) emissions were all greater than the critical value, yielding statistically significant p-values of 0.010, 0.048, and 0.042, respectively. No correlation is observed between the number of COVID-19 cases and the amount of dust, CO, HF, TOC, and CO_2 emitted. The results are puzzling because the exhaust gas cleaning device does not remove CO_2. The CO_2 value may be related to the use of fuel oil to initiate the waste incineration process and to maintain the process. In the case of small amounts of waste, oil is added to the thermoreactor of the analysed incineration plant (as auxiliary fuel) to carry out effective disposal. Burning oil involves additional CO_2 emissions. The lack of correlation between the amount of COVID-19 cases and the amount of CO_2 emitted can be caused by less oil added to the incineration process when a large amount of waste is utilised. Hence, the amount of CO_2 emitted when burning covid waste somehow replaces the CO_2 emissions associated with the addition of oil when burning non-covid waste.

Analysing the values of Pearson linear correlation coefficient for the statistically significant variables: SO_2, NO_x, HCl, which are 0.6256, 0.5019, 0.5130, respectively we find that they are in the range $0.4 < |r_{XY}| < 0, 7$, indicating a moderate correlation. It can be seen that the correlation is the strongest for SO_2, while for the other two statistically significant pollutants (NO_x, HCl), it is at a similar level. Determining the moderate correlation for SO_2, NO_x, and HCl pollutants draws attention to air pollution problems during the COVID-19 pandemic. In addition, it allows managers of medical waste incineration plants to analyse whether there is a need for additional air purification devices. The limitation of the study is the length of the analysed period. More extended, longer observation of the relationship between the number of COVID-19 cases and the number of pollutants emitted from medical waste incineration plants could show a correlation between the other analysed variables. Monitoring of pollutant emissions during the COVID-19 pandemic should continue. Below (Fig. 5) the statistically significant variables (SO_2, NO_x, HCl) and the number of COVID-19 cases in the period March 2020–June 2021 are presented in a graph.

4 CONCLUSIONS

A properly functioning medical waste incineration plant is an entity that takes care of human health and the environmental cleanliness in terms of air protection. The analysis of pollutant emissions from the medical waste incineration plant shows that the plant disposes of waste properly. The devices reducing the emission of pollutants operate efficiently and are compatible with the continuous monitoring system.

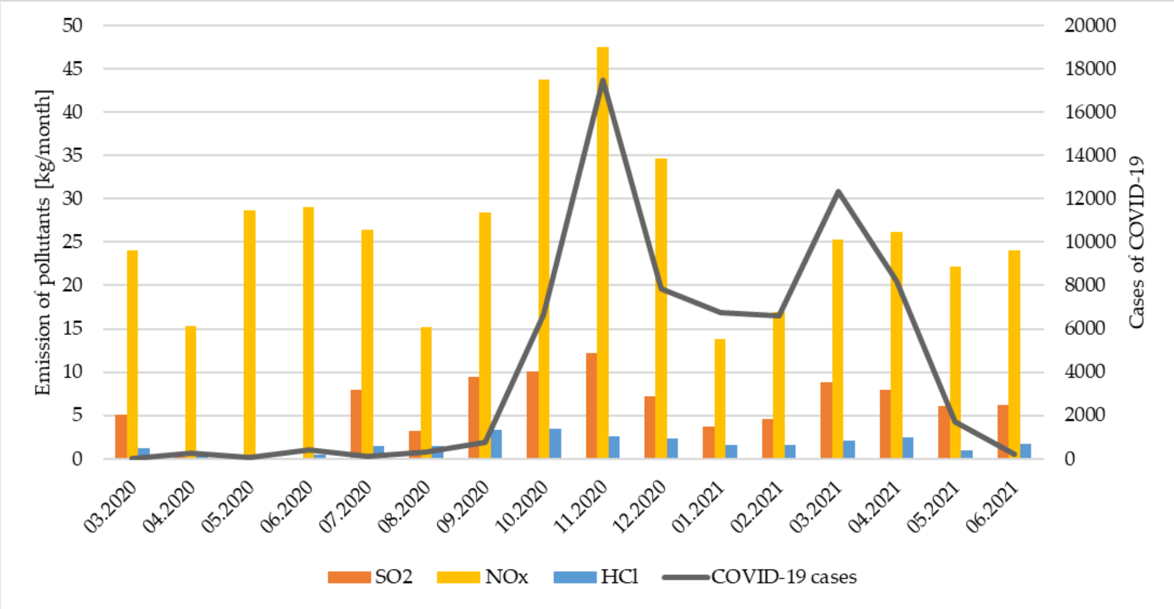

Fig. 5. The concentration of SO_2, NO_x, HCl in exhaust gas emitted from medical waste incineration plants and the number of COVID-19 cases in Podlaskie Voivodeship.

Statistical analysis shows that the amount of covid medical waste that goes to incineration plant correlates moderately with the number of COVID-19 cases, with a statistically significant correlation coefficient of 0.5140. This result is the starting point for analysing an indirect relationship: the number of COVID-19 cases and the number of pollutants emitted into the air. Eight pollutants are considered in the analysis of emissions from medical waste incineration: dust, SO_2, CO, NO_x, HCl, HF, TOC, and CO_2.

Statistical analysis show that in the study sample, i.e., the 16-month period of the COVID-19 pandemic from March 2020 to the end of June 2021, only emissions of SO_2 ($p = 0.010$), NO_x ($p = 0.048$) and HCl ($p = 0.042$) were significantly correlated with the number of COVID-19 cases. The correlation coefficient values for the above pollutants are in the range of $0.4 < |r_{XY}| < 0.7$, which means that the emissions of these pollutants are moderately associated with the number of COVID-19 cases. The strongest correlation among the three statistically significant pollutants is observed for SO_2.

It is concluded that the COVID-19 pandemic has a moderate effect on the increase in air pollutant emissions from medical waste incineration plants in Podlaskie Voivodeship, Poland. It would be a good practise to carry out an energy balance of the analysed incineration plant and try to use the thermal energy generated during the incineration of medical waste, which would have a positive ecological effect.

ACKNOWLEDGMENTS

The authors express their sincere thanks to the Ministry of Science and Higher Education of Poland for research and APC funding (resources for young researchers WI/WB-IIŚ/13/2020 and WZ/WB-IIŚ/7/2022). Moreover, the authors wish to thank Provincial Inspectorate of Environmental Protection in Białystok for providing data on the emission of pollutants from medical waste incineration plant (public information).

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