Kamil Krzysztof ROMAN[1], **Kinga BOREK**[2], **Kamila MAZUR**[2], **Witold Jan WARDAL**[2]

Warsaw University of Life Sciences, Institute of Wood Sciences and Furniture (1),
Institute of Technology and Life Sciences, Branch in Warsaw (2)

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The measurements of $PM_{2.5}$ dust concentration by using an integrated optical sensor

Abstract: *Dust measurement depends of analog value of voltage read is equal to the PM2.5 dust concentration. The recorded values were analyzed by the ANOVA multivariate analysis. During the statistical analyzes, it was found the relative humidity influence on the PM2.5 dustiness level. The influence of the air temperature on the PM2.5 dust emissions was also found.*

Streszczenie. *Pomiar zapylenia zależy od wysokości odczytanego napięcia na wyjściu analogowym i odpowiada wartości stężenia pyłów $PM_{2.5}$. Określone podczas pomiarów wartości jako czynniki materiałowe surowca poddano analizie statystycznej wykorzystując metodę wieloczynnikowej analizy wariancji ANOVA. W świetle analiz statystycznych stwierdzono, że istnieje wpływ wilgotności względnej na poziom zapylenia $PM_{2,5}$. Dodatkowo, zaobserwowano wpływ temperatury powietrza na poziom emisji pyłów $PM_{2,5}$.* (***Pomiar pyłu $PM_{2,5}$ z wykorzystaniem elektronicznego zestawu z zintegrowanym czujnikiem optycznym***).

Keywords: PM2.5, dust, electronic equipment, ANOVA, optical sensor
Słowa kluczowe: PM2,5, pyły, urządzenie elektryczne, ANOVA, sensor optyczny

Introduction

Dust pollution is one of the most hazard forms of air pollution. Every human activity and environmental effects can affect on the dust level emissions. Especially transport that is primarily responsible for long range pollutants, what was confirmed in the studies from Asia [1, 2]. The particulate matter (PM) can come from primary or secondary sources, and be formatted in natural causes (plant dusting, aerosols and soil erosion) or by the impact of human activity (soot, fly ash and cement dust) [3]. Dust should be understood as a collection of solid particles that have been thrown into the atmosphere and remain in it for a certain period of time [4]. There are five main categories of dust emission sources, including: power industry, industrial energy, industrial technologies, other stationary sources (e.g. boiler rooms and home furnaces) and mobile sources [5]. The largest amounts of dust get into the air from such industries as energy, chemical, mining, metallurgy and construction. According to above, the practice of gas cleaning from dust is very important during the industry processes (e.g. ferrous and non-ferrous metallurgy, metal, wood, plastic processing), municipal (solid fuel combustion, ventilation and air conditioning installations) [6] also in agriculture (e.g. from animal production or combustion of straw). The increase in dustiness has accompanied us for many years causing the atmospheric radiative balance and climate change. In literature can be found the analysis of dust emissions impact on climate change. In article about application the Weather Research and Forecasting model the evaluation of meteorological variables and dust emissions in the years 1980–2015 over East Asia was measured [7].

The dust classification is based on particle sizes and their impact on human health. Total suspended particulate (TSP) means the total dust contained in the atmospheric air. PM10 (particulate matter) is the fraction sampler with a particle size below 10 µm. PM2.5 is a fraction of particulate matter with a colloidal fineness that particle diameters are smaller than 2.5 µm. Particulate matter with a diameter below 2.5 µm (called fine dust) could reach the upper and lower respiratory tract and can enter the blood. The PM10 dust can cause coughing, breathing difficulties and shortness of breath. The greatest danger is the fine-shaped particles floating with the air. The fact that the structure of dust as well as the fractionality has a great impact on their displacement, spatial and climatic conditions has an important role. The dust share depends on place. Studies described in the literature [8] prove that the dust share has a negative effect on air quality, both inside and outside the building. The highest concentration of dust is recorded in closed places with low ventilation, as well as on surfaces with increased work, e.g. reloading and unloading. One of the main climatic factors affecting the movement of small particles in the air is strong wind and low humidity.

According to the recommendations, dusts must be controlled and reduced to protect the environment, human and animal health and welfare. For health safety reasons, local authorities and local government units are intensifying their efforts to reduce PM2.5 dust emissions. Therefore, an acceptable level of PM2.5 dust has been established per year, which should not exceed 25 µg/m^3 [9]. The following classification of suspended dust with a diameter of 2.5 µm (PM2.5) and 10 µm (PM 10) is used in air quality control [10]. The European Union in the field of air quality is forcing to developed the control mechanisms (European Directives 1996/62/EC, 1999/30/EC, and 2008/50/EC) and dust reduction strategies (Official Journal of the European Union 2017). Directive 2008/50/EC sets target and limit values for PM2.5 concentrations in Europe, dividing them into ambitious, economically viable to improve human health and the quality of the environment by 2020. The directive also specifies ways of assessing the corrective actions taken and goals in the event of failure to meet the assumed standards. The document sets out the separate indicator for urban areas (average exposure indicator), requiring the public to be informed of the hazards associated with pollination [11].

The National Center for Emissions Balancing and Management (KOBIZE) is a unit reporting the amount of pollution released into the atmosphere. The amount of dust emissions every year is estimated in the KOBIZE reports titled "National Emission Balance of SO_2, NO_x, CO, NH_3, NMVOC, Dust, Heavy Metals and POPs in the SNAP and NFR classification system". The amount of air pollution is based on the structure of emission sources contained in the "EEA/EMEP Emission Inventory Guidebook" [12], in the SNAP classification system. The share of PM2.5 dust emissions in individual years was 7.25, 6.22, 1.51 and 9.68%. Emission of PM2.5 dust from selected sources in 2012-2015 is presented in Table 1.

Table 1. Dust emissions from PM2.5 fraction in 2012-2015 [13, 14]

Source of issue	PM2.5 emission [Mg]			
	2012	2013	2014	2015
Total	144 771	144 510	125 520	124 562.5
Combustion processes in the energy production and transformation sector	14 901	14 932	13 404	13 411
Combustion processes outside industry	71 679	73 498	67 102	66 030
Agriculture	512	339	486	549
	0.35%	0.02%	0.39%	0,44%

There are several simple methods for reducing dust emissions. One of them is the use of windbreaks in the form of a row of densely planted trees that have a positive effect on soil erosion. Speed limiting on unpaved roads and watering them before starting heavy farm work is also a recommended way to reduce dust. According to literature studies [15] the use of resins or petroleum derivatives used on roads. Despite the high costs, this method effectively reduces dust during traffic. Pollution reduction can also be achieved by using local resins, oils or vegetable waste (e.g. straw, hay or sawdust), thus reducing water evaporation. The prepared surface absorbs energy during pressure on the soil.

In addition, in order to maintain high air quality, systems that monitor air purification require continuous monitoring of their effectiveness in practical conditions. Standardized measuring devices, as well as measuring procedures for quantifying the level of dust in the air, require deep analysis. It is necessary to validate and adapt the equipment to the samples taken during the measurement [16]. Measurements of concentration and emissions should include monitoring the size of dust particles due to the negative impact of dust on human life. The tests carried out in the field of measuring dustiness will help estimate the accuracy of the devices used. Thanks to the applied sensors integrated with a specially designed device, dust emissions in a given area will be determined.

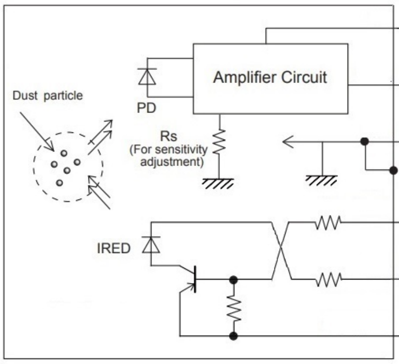

Fig. 1. Connection diagram for the GP2y10147x23 module Source. Based on GP2y10147x23 datasheet

Methodology

The tests were carried out in laboratory conditions, which included the PM2.5 dust measuring device. The PM2.5 dust measurement method that was used is based on optical concentration measurement. The device used is equipped with a module containing an infrared emitting diode (IRED) and a phototransistor arranged in a specific position. The action is based on detecting the reflected light passing through the airborne dust. The sensor detects PM2.5 particles. The module used was in accordance with the RoHS Directive (2002/95/EC). The dimensions of the module used were 46.0 × 30.0 × 17.6 mm, while the module itself had a weight of 15g. The maximum current consumption (Icc) is 20 mA, with a supply voltage (DC) of 5.2V, with a sensitivity of 0.5 V / 0.1 mg / m^3. The operating temperature of the device should be between -10 to 65°C. The diagram of the GP2y10147x23 measuring module is shown in Figure 1.

The measurement result was read using an analog output, where each increase in voltage by 0.5V corresponded to a proportional increase in PM2.5 dust by 100 µg/m^3. The usage of ADC (Analog to Digital Converter) allowed determining the characteristics of PM2.5 dustiness. The permissible measuring range for PM2.5 was 500ug / m3. Diagram of voltage dependence on PM2.5 concentration is presented in Figure 2

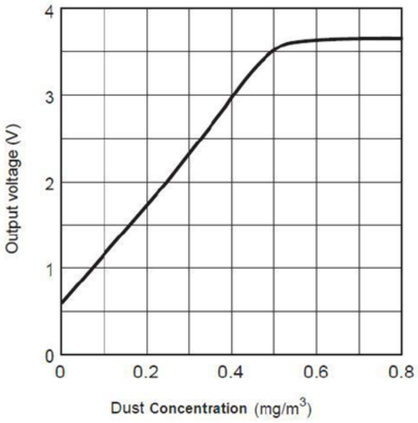

Fig. 2. Voltage dependence on PM2.5 dust concentration Source. Based on GP2y10147x23 datasheet

The module's practical operation consisted of generating an IR signal in 0.32 ms and a period of 10 ms. The signal after moving through the set of lenses and penetrating the measured area went to the phototransistor. All elements of the module were placed relative to each other at an appropriate angle. The value of radiation received by the photoresistor was directly proportional to the amount of dust concentration in the air. The length of IR radiation was controlled by a pulse generator directly coupled to the measuring module. The recorded ADC voltage after 0.28 ms was read as an analog signal from the DATA port. The analog output has been connected to the device controlling the height and frequency of the signal filling. The value of the received voltage should be multiplied by 11, which resulted from the voltage divider used in the module of 1kΩ/10kΩ [17]. Block diagram of connecting all elements of the measuring module is presented in Figure 3

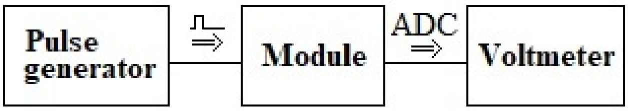

Fig. 3. Block diagram of connecting all elements of the measuring module

Dust height was tested in laboratory conditions taking into account environmental factors such as air temperature (*T*) and relative humidity (*RH*). The environmental factors tested were measured using a LAB-EL LH-706 thermohygrometer. The hytherograph works with specialized probes to measure selected environmental parameters. It is possible to send the collected measurement data to an external device via a serial communication interface [18]. The readings of the air temperature and relative humidity were subjected to statistical analysis comparing the obtained data with the obtained dustiness level.

Analytical tools in the form of multivariate ANOVA analysis were used for statistical analysis of laboratory test results. The method allowed to determine the influence of variables of unit belonging to a specific group on the value of the examined variable. The factors were air temperature values and relative humidity. Groups of factors were compared with one classification criterion. The significance of differences and the magnitude of the impact of the quality condition were determined. The influence of arguments allowed to show a group of statistically significant factors that affect the examined parameter. The specified groups of factors were compared with the assumed classification criteria.

During the analysis, α was taken into account, characterizing the level of significance, expressing the probability of making an error in the selection of the confidence factor. The value of α was adopted at the level of 0.05. The value of α was the difference between unity and the confidence factor F, which was 0.95, i.e. F = 1-α. The results of the statistical analysis were also affected by the nature of the problem and the accuracy of the distribution of means [18]. The determination of the resulting intergroup error consisted in determining the ratio of the sum of intergroup squares to the number of degrees of freedom. Theoretically, an intergroup error can be determined using formulas (1), (2) and (3) [20].

$$SS_T = \sum_{i=1}^{a} m_i \left(\bar{y}_{(i..)} - \bar{y}_{(..)}\right)^2 \tag{1}$$

$$df_T = a - 1 \tag{2}$$

$$MS_T = \frac{SS_T}{df_T} \tag{3}$$

where: m_i - the number of units in individual groups, a - the number of compared groups in the analysis of variance, the number of factor levels, $\bar{y}_{(..)}$ - general average, for all observations, $\bar{y}_{(i..)}$ - average for a given factor level for the examined group, SS_T - a sum of squares between objects, between groups, df_T - degrees of inter-object and inter-group freedom, MS_T - intergroup variance.

The results prepared in tabular form will give a clear view on the sources of the formation of adverse emissions, as well as the possibilities of their individual reduction. As a result, based on the results of the research, there is a high probability of the possibility of rapid refinement of methods to reduce PM2.5 emissions.

Analysis of results

The test results were statistically analyzed determining the impact of environmental parameters on the level of PM2.5 dust emission. During statistical analyses, one-way ANOVA variance analysis was used. First, measurement was carried out to determine the effect of relative humidity on PM2.5 dust emissions. Statistical analysis showed the presence of relative humidity on the level of PM2.5 dust emissions. The level of significance, in this case, was p = 0.00001, for the empirical value of statistics F (2.195) = 12.704. The results of the statistical analysis are presented in Figure 4.

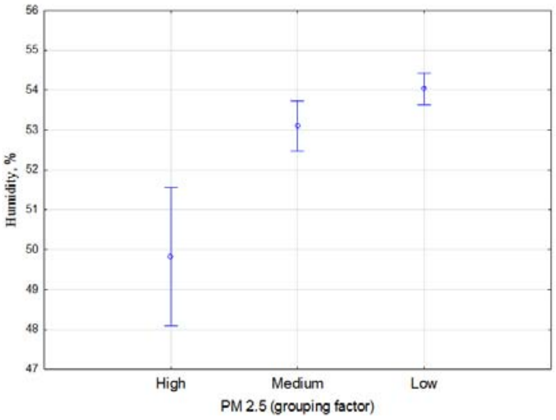

Fig. 4. The impact of relative humidity on the level of PM2.5 dust emissions

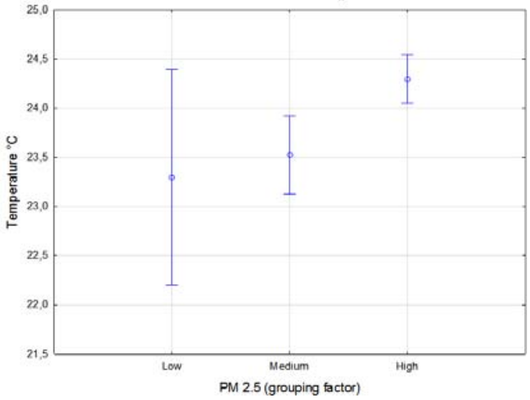

Fig. 5. Impact of air temperature on PM2.5 emissions

In the figure above, the confidence intervals can be read as vertical bars having a range of 0.95. Confidence intervals can be determined for the arithmetic mean. The probability determining the actual location of specific parameters was determined by the confidence factor (1-α) (100% confidence interval (1-α)) [18]. The method combined in special cases with the post-hoc test allows you to determine the belonging of the analyzed parameters of the distribution of the random variable on the basis of interval estimation, which means assigning numerical values for a certain range with some estimated probability [21].

The numerical range estimated with assumed probability as a confidence interval contained an unknown, true value of the parameter belonging to the general population. Duncan's post-hoc test used involved comparing the control variable with individual groups of factors, assigning variables to individual homogeneous groups [22]. The approximate probabilities in the Duncan test (post hoc) carried out as part of the statistical analysis of the effect of relative humidity on PM2.5 emissions are presented in Table 2.

Table 2. Approximate probabilities of the impact of relative humidity on the PM2.5 emission level

PM2.5 emission level (grouping factors)	Homogeneous group		
	I	II	III
High		0,000036	0,000011
Medium	0,000036		0,236602
Low	0,000011	0,236602	

The impact of air temperature has an impact on the level of PM2.5 dust emissions, was observed. The degree of significance *p* = 00230 for the empirical value of statistics *F*(2.195) equals 6.2687. The graph illustrating the interaction of the studied parameters was presented in Figure 5.

According to the methodology, a statistical test was performed determining the belonging of the parameters in the form of the influence of air temperature to appropriate homogeneous groups. The approximate probabilities in the Duncan test carried out as part of the statistical analysis of the impact of air temperature on PM2.5 emissions are presented in Table 3.

Table 3. Approximate probabilities of the impact of relative humidity on PM2.5 emissions

PM2.5 emission level (grouping factors)	Homogeneous group		
	I	II	III
High		0.648744	0.054690
Medium	0.648744		0.116699
Low	0.054690	0.116699	

Summary and Conclusions

The largest amounts of dust get into the air from such industries as energy, chemical, mining, metallurgy and construction. Dust gas cleaning is important in a wide variety of heavy industry processes (e.g. ferrous and non-ferrous metallurgy, metal, wood, plastic processing), municipal (solid fuel combustion, ventilation and air conditioning installations) [6] and in agriculture (e.g. from animal production or combustion of a straw).

The results of PM2.5 dust analysis in relation to relative humidity showed the existence of influence. The level of significance, in this case, was p = 0.00001, for the empirical value of statistics $F(2, 195)$ = 12.704. The approximate probabilities of the effect of relative humidity on the PM2.5 emission level confirmed the existence in two cases where the significance level was below 5%. In the case of the impact of air temperature on PM2.5 dust emissions, an effect was also observed. The degree of significance in this case p was 00230, while the empirical value of F (2.195) equals 6.2267.

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***Authors**: Ph.D. Eng. Kamil Roman,* Warsaw University of Life Sciences*,* Institute of Wood Sciences and Furniture*,* Nowoursynowska 159, building 34, room 2/14B, 02-776 Warsaw*, E-mail: kamil_roman@sggw.pl; M.Sc. Eng. Kinga Borek,* Institute of Technology and Life Sciences, Branch in Warsaw*, Department of Rural Technical Infrastructure Systems, Rakowiecka 32, 02-532 Warsaw, E-mail: k.borek@itp.edu.pl; Ph.D. Eng. Kamila Mazur,* Institute of Technology and Life Sciences, Branch in Warsaw*, Department of Rural Technical Infrastructure Systems, Rakowiecka 32, 02-532 Warsaw, E-mail: k.mazur@itp.edu.pl; Ph.D. Eng. Witold Jan Wardal,* Institute of Technology and Life Sciences, Branch in Warsaw*, Department of Rural Technical Infrastructure Systems, Rakowiecka 32, 02-532 Warsaw, E-mail: w.wardal@itp.edu.pl*

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