JEE Journal of Ecological Engineering
Volume 21, Issue 1, January 2020, pages 180–187
https://doi.org/10.12911/22998993/112764

Received: 2019.09.02
Revised: 2019.10.14
Accepted: 2019.11.30
Available online: 2019.12.20

The effect of selected meteorological factors on the process of "Polish smog" formation

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ABSTRACT

The phenomenon of smog, i.e. excessive air pollution in urban areas is well-known and has been widely described in the literature. Typically, two types of smog are distinguished: the acid smog that is called "London smog" and the photochemical smog called "Los Angeles-type smog". The first one is formed in the winter months. In contrast, the photochemical smog arises in the summer months. In recent years in Poland, especially in winter, alarms associated with poor air quality have become very common. Under Polish climatic conditions, the main reason for low air quality corresponds to the exceeded permissible concentrations of suspended particulate matter. The paper analyzes the process of "Polish smog" formation by comparing the recorded concentrations of PM10 suspended particulate matter at four monitoring stations of the Inspectorate of Environmental Protection with weather conditions prevailing at that time. The data from the monitoring stations located in four Polish cities: Krakow, Zabrze, Lodz and Gdansk were analyzed. The analysis covered the years 2014–2017. The results of this analysis showed that "Polish smog" arises under different meteorological conditions than other types of smog known from the literature.

Keywords: smog, particulate matter PM10, Polish smog

INTRODUCTION

For several years in the winter season, we have noticed significant exceedances of the permissible air pollution levels in Poland. This applies above all to PM10 suspended particulate matter, PM2.5 respirable dust and benzo(a) pyrene which is a representative of the whole group of very toxic (mainly carcinogenic) chemical compounds – polycyclic aromatic hydrocarbons (PAHs) [Megido et al., 2016, Mishra, 2017, Wong, 2017]. Occurring in the winter months, very high concentrations of the above-mentioned pollutants are often associated with the known case of the Great Smog of London in December 1952, which lasted for several days and killed about 12,000 residents of the Great Britain's capital [Witchmann, 2004]. Comparing the cases of London-type smog (so-called "acid smog") described in the literature with the smog episodes observed in Poland for several years, it is easy to see that the most dangerous component of London smog was sulfur dioxide (next to carbon monoxide and particulate matter) [Mira-Salama et al., 2008, Zhou et al., 2015], whereas in the case of the Polish smog episodes, no exceedance of the permissible levels of immission of these pollutants is observed. Thus, this is the first and so far the most important difference between the analyzed phenomena related to high concentrations of atmospheric air pollutants. This allows us to talk about the smog occurring in Poland which is different than the London-type smog. It was proposed to describe the phenomenon occurring in our country with the term "Polish smog". According to the literature, the London-type smog occurs in humid low-pressure areas, light winds or windless weather and temperatures ranging from 0 to +10°C [Chu, 2004, Kim et al., 2007]. In this case, the source of pollution is the combustion of low-quality solid fuels, mainly coal, in individual heating systems, concentrated in the centers of urban agglomerations. The pollutants emitted from the combustion processes under temperature inversion conditions accumulate at the ground surface forming, in combination with fog, drops of acid aerosol [Rodriguez et al., 2016, Wang et al., 2017, Yang et al., 2017]. The observations carried out in Poland indicate that the London-type smog occurs in winter, but relatively rarely, while the periods of high concentrations of pollutants occur much more often, also under other meteorological conditions On the basis of the observations from 2014–2017, the thesis that the largest exceedances of permissible concentrations of suspended particulate matter in Poland are observed at high temperature, sunny weather and the inflow of frosty air from the east has been put forward. It was decided to prove this thesis by analyzing the correlation between the suspended particulate matter concentrations as well as the air temperature and atmospheric pressure in various regions of Poland.

DESCRIPTION OF THE PROBLEM

The impact of meteorological factors, such as temperature and atmospheric pressure, on the formation of Polish smog – the occurrence of excessive PM10 concentrations was analyzed in the study.

The PM10 immission data from the measurement data bank of the Chief Inspectorate of Environmental Protection in Poland from 4 stations located in different parts of the country were used in the analysis. The exact location of the stations is shown in Figure 1.

The choice of weather stations is not accidental. According to the results of the research by Rawicki et al. [Rawicki et al., 2018] Poland, due to the occurrence of smog episodes, can be divided into 3 regions – southern, where these episodes occur most often and last the longest, central with moderate frequency of smog episodes, and northern, where smog incidents occur sporadically. For the southern region, meteorological stations and VIEP air quality measuring stations in Kraków and Zabrze were selected for analysis as representative, Lodz was selected for the central region, and Gdansk for the northern region. Their basic characteristics are given below.

The first measuring station is located in northern Poland in the city of Gdansk. It is a station with an automatic measurement system located 51 m a.s.l. It measures the following parameters: carbon monoxide, nitrogen dioxide, nitrogen oxides, PM10 suspended particulate matter and sulfur dioxide in urban areas. It was launched in 1996.

Another measuring station is located in central Poland, in Lodz. It is a stationary container station with automatic measurement, located 206 m a.s.l. The station is surrounded by compact multi-family residential buildings as well as commercial and service facilities. The main source of emissions in the vicinity of the station is the combustion of fuels in commercial and

Fig. 1. Location of measuring stations on the map of Poland

residential buildings. It was launched in 2012. It monitors the immission of the following pollutants: sulfur dioxide, nitrogen oxides, nitrogen dioxide, carbon monoxide, benzene, ozone, PM2.5 and PM10.

The third measuring station is located in the south of the country, in Krakow. It was launched in 2003. It is equipped with the devices for measuring carbon monoxide, nitrogen dioxide, nitrogen oxides, PM10, PM2.5, benzo(a)pyrene in PM10 and benzene. It is located 207 m a.s.l. in a street canyon.

The last measuring station is also located in the southern part of the country, in the town of Zabrze. Its surroundings are free-standing buildings and compact buildings. It is located at an altitude of 255 m above sea level. It automatically measures PM10, sulfur dioxide, carbon monoxide, nitrogen dioxide, nitrogen oxides and ozone. It was launched in 2001.

RESULTS

While analyzing the monitoring data, an attempt was made to find a correlation between the meteorological factors (air temperature, atmospheric pressure) and immission of pollutants (recorded PM10 concentrations). The analysis covered the data from all the above-mentioned monitoring stations in the years 2014–2017. The measurement data from winter months (December, January, February and March), i.e. the period where smog incidents occur most often, were taken into account. The dependence of the PM10 concentration on air temperature in subsequent years is illustrated in Figures 2 to 5.

A clear correlation between the PM10 concentration and the air temperature can be seen in all these Figures. The concentration of PM10 decreases as the air temperature increases. It can also be seen that the highest concentrations of PM10 occur at the temperatures between -5 and -10°C.

The atmospheric pressure was another meteorological factor analyzed. The dependence of PM10 concentration on atmospheric pressure in individual years is illustrated in Figures 6 to 9.

There is also a clear relationship between the PM10 concentration and atmospheric pressure. It is opposite than in the case of temperature. The higher the atmospheric pressure the higher the PM10 concentration. The highest concentrations of PM10 can be observed under high pressure conditions, at the atmospheric pressure ranging from 990 to 1030 hPa.

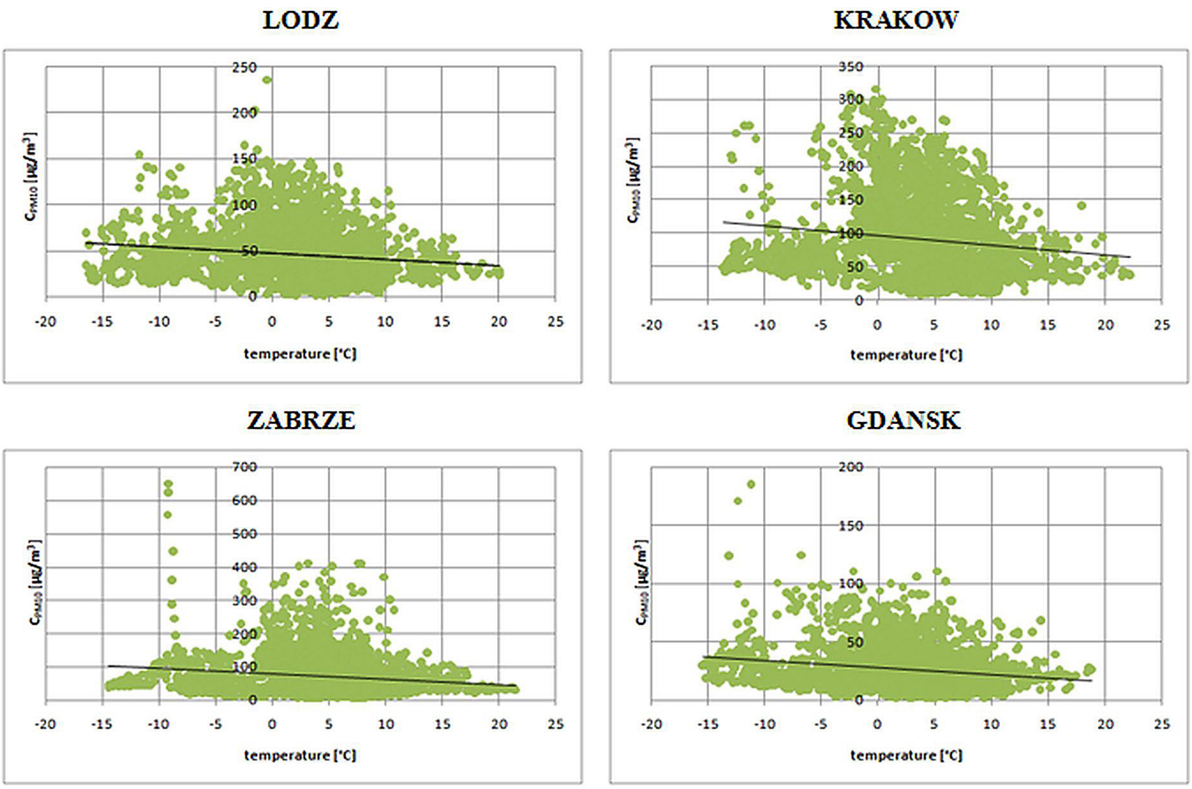

Fig. 2. Dependence of PM10 concentration on temperature in 2014

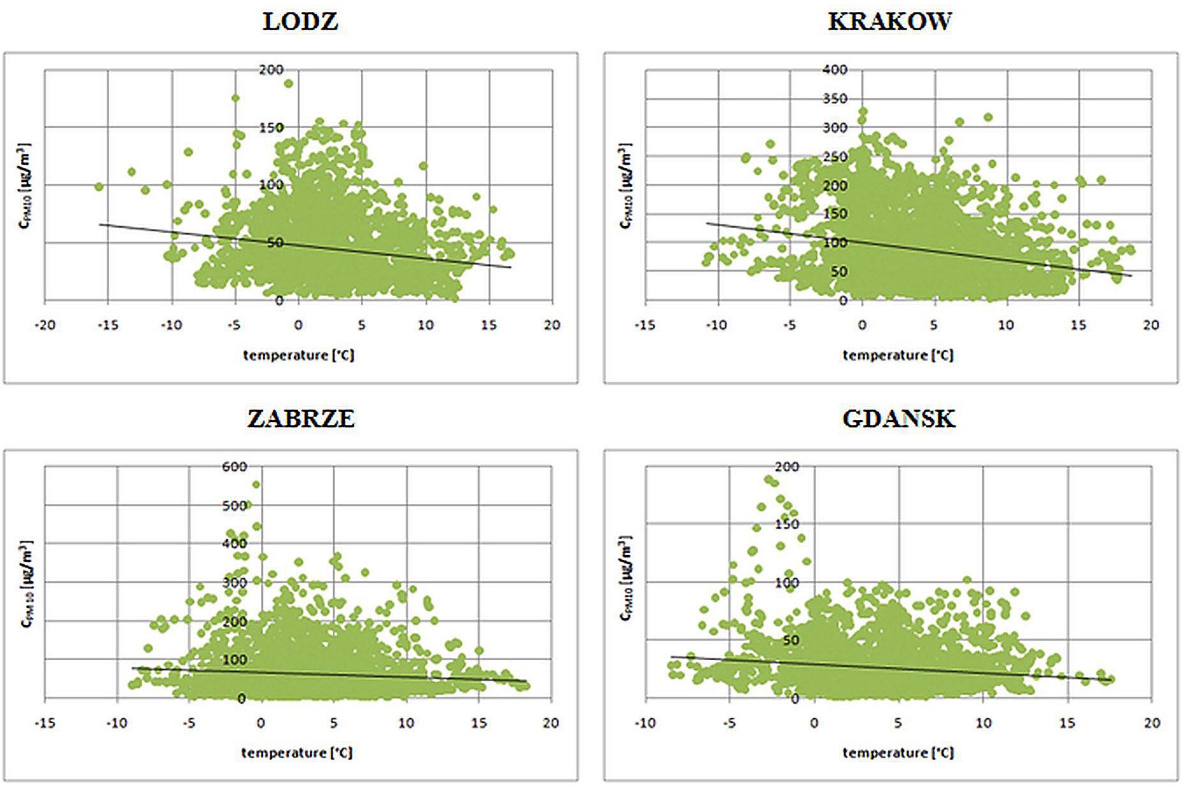

Fig. 3. Dependence of PM10 concentration on temperature in 2015

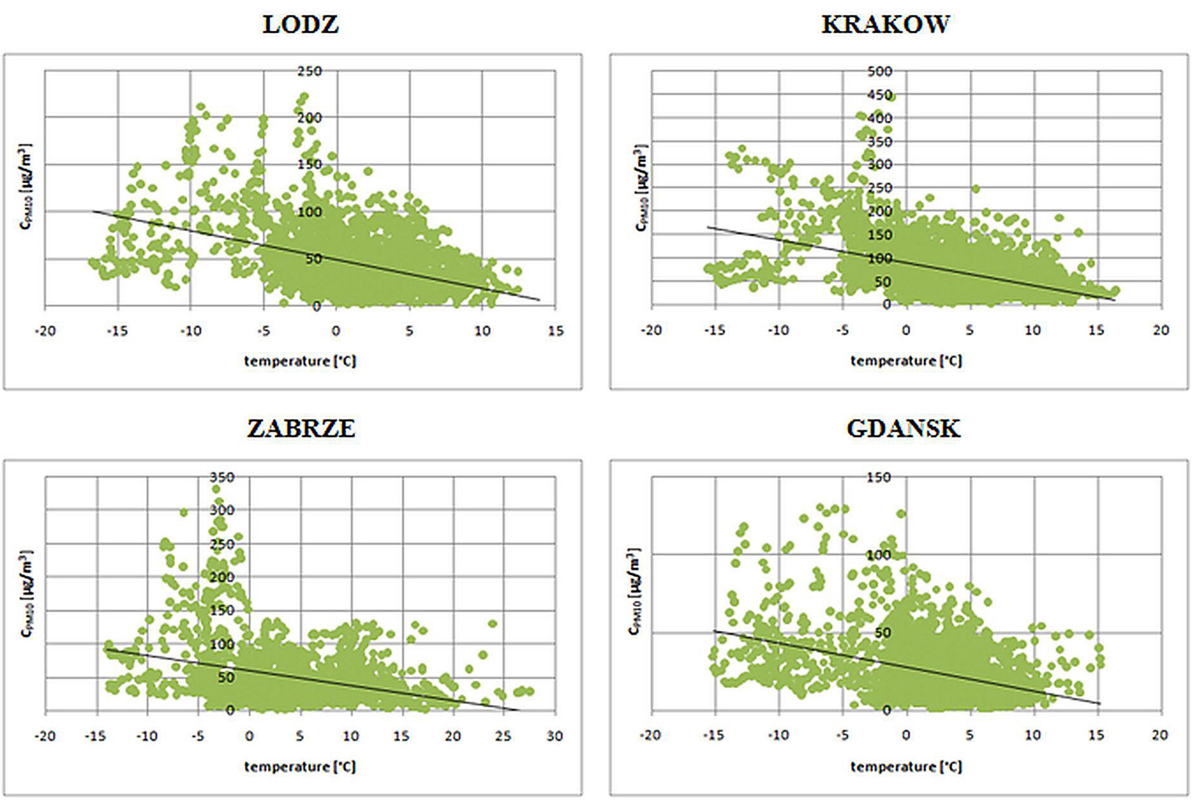

Fig. 4. Dependence of PM10 concentration on temperature in 2016

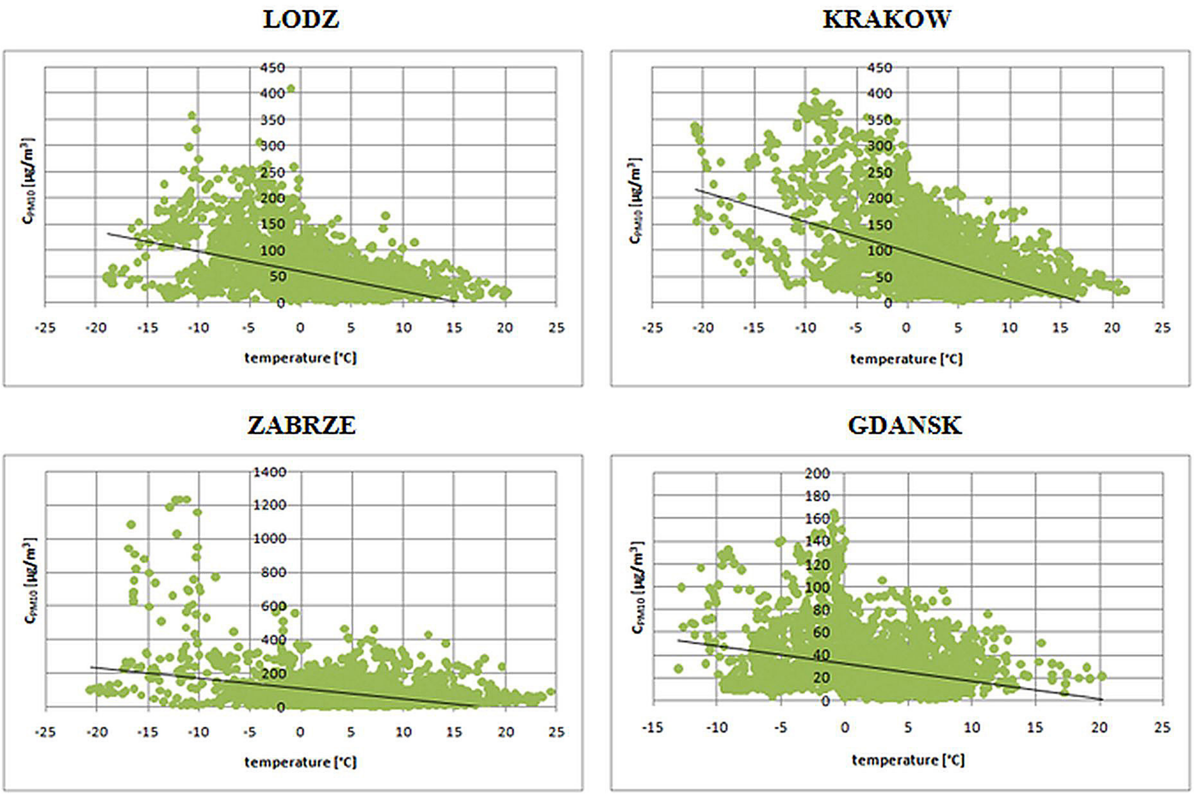

Fig. 5. Dependence of PM10 concentration on temperature in 2017

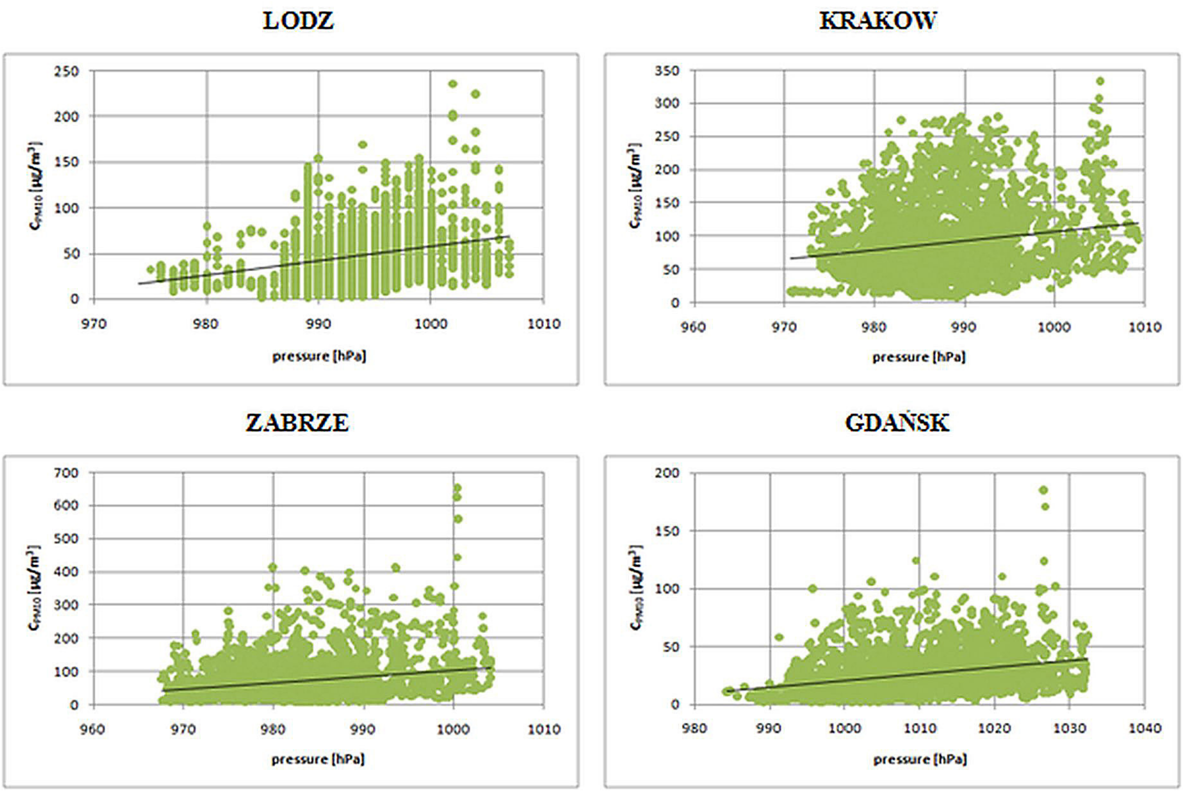

Fig. 6. Dependence of PM10 concentration on pressure in 2014

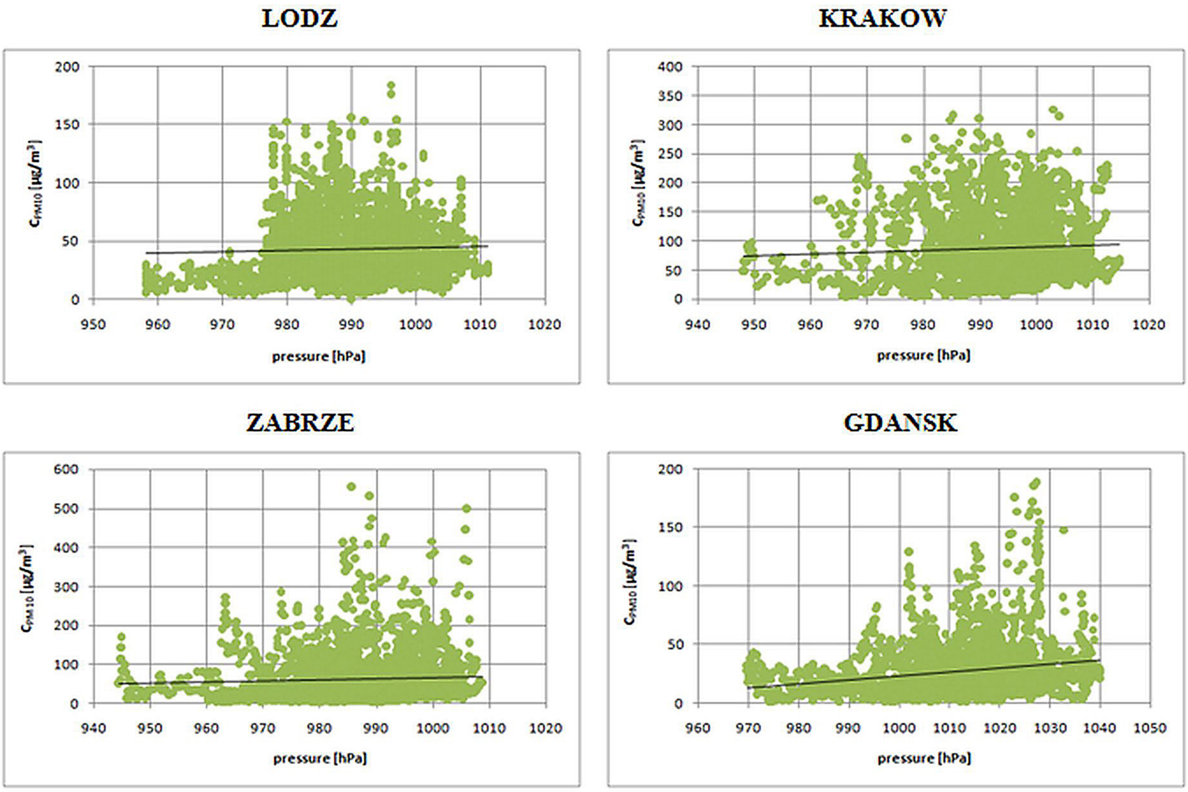

Fig. 7. Dependence of PM10 concentration on pressure in 2015

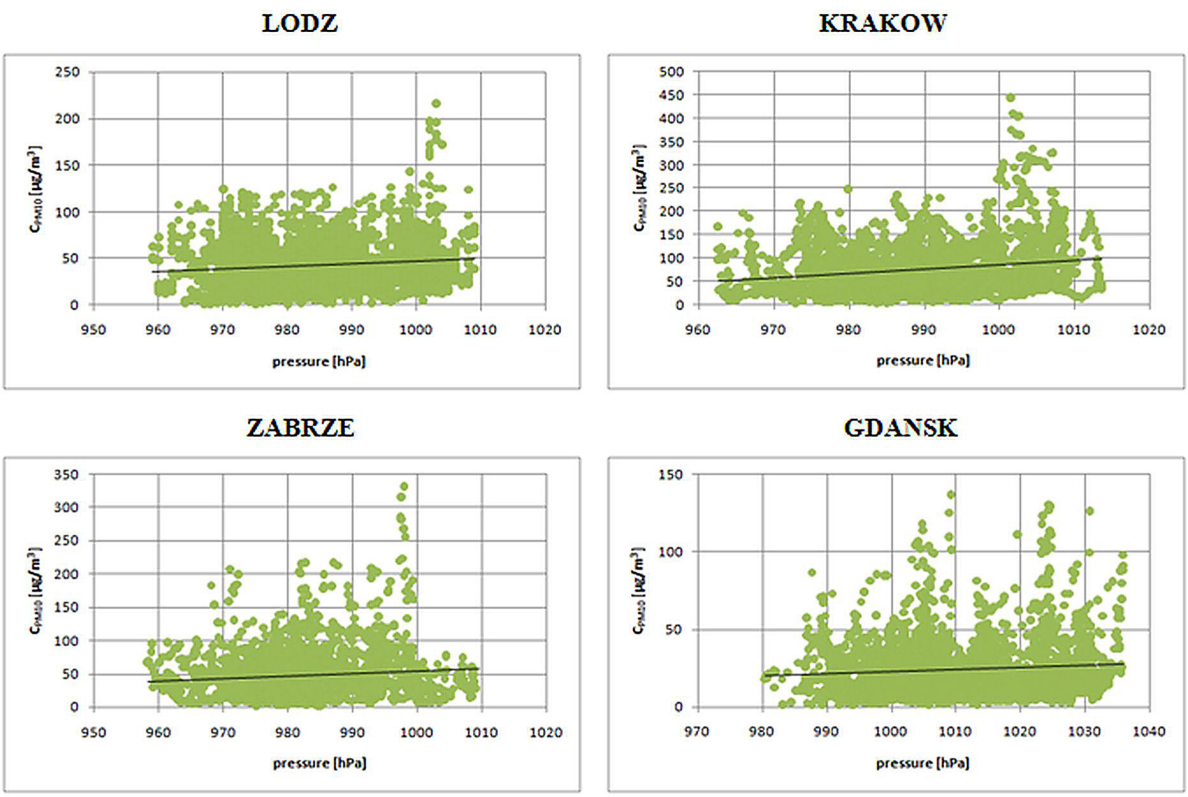

Fig. 8. Dependence of PM10 concentration on pressure in 2016

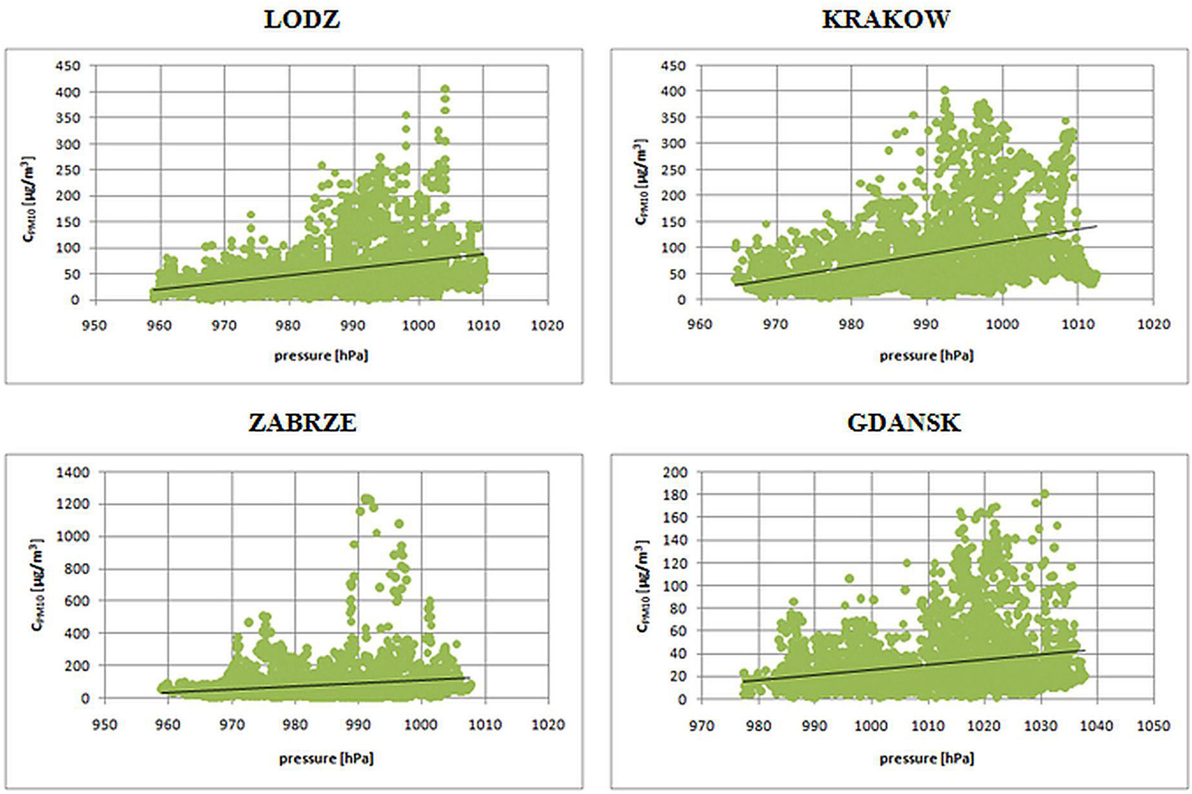

Fig. 9. Dependence of PM10 concentration on pressure in 2017

CONCLUSIONS

The immission (concentration) of suspended particulate matter PM10 in 2014–2017 in four Polish cities: Gdansk, Lodz, Krakow and Zabrze was analyzed in the study. The analysis was based on the results of environmental monitoring of the Chief Inspectorate of Environmental Protection in Poland. It was found that there is a clear dependence of the recorded PM10 concentrations on the meteorological conditions. At all stations, it was observed that the concentration of PM10 decreases with increasing air temperature and increases along with the atmospheric pressure. These results lead to the thesis that Polish smog differs from other ones described in the literature, e.g. acid London smog and photochemical smog [Muiwijk et al., 2016]. The specific feature of the Polish smog is the presence of high concentrations of PM10 at high-pressure weather and negative temperatures. In Poland, such conditions often occur in winter, when sunny high-pressure weather from Russia sends frosty air masses to Poland. At low winds, in the often occurring snow cover, at night there are very strong temperature drops at the ground, which promotes the formation of temperature inversion, which in turn significantly hinders the spread of pollutants in the atmosphere. In addition, at low temperatures, larger amounts of fuel are used in heating systems, which results in increased emissions. Due to the height of emitters, the increased emissions from organized sources of electricity and heat supply (combined heat and power plants, municipal and district heating plants) do not significantly affect the increase in concentrations near the ground surface and thus practically do not affect smog formation. The emissions from individual heating systems are of decisive importance here, when the places of introduction of pollutants into the air are much lower than the height of the inversion layer.

It can therefore be assumed that the occurrence of excessive concentrations of suspended particulate matter PM10 and respirable dust PM2.5 and benzo(a)pyrene (as a representative of PAHs) in the winter months in Poland can be called “Polish smog”, unlike the London-type smog or the Los Angeles-type smog, due to a different set of pollutants (e.g. no SO_2 exceedances compared to the London smog) and other favorable weather conditions.

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