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METHODOLOGICAL ASSUMPTIONS FOR MODELLING THE SPREAD OF POLLUTANTS IN THE AIR FROM INCIDENTAL WASTE FIRES

Summary

The article presents the possibilities of applying the methodology of modelling the spread of pollutants in the air for the processes of uncontrolled waste combustion with the use of the Gaussian Dispersion Model (1st generation plume), simultaneously modifying the assumptions for input data in regard to the degree of emission and meteorogical parameters assumed for modelling. The model has been adapted to parameters of the assumptions of the Source Characterisation Model (SCM). The publication indicates the suitability of using the described methodology in specific conditions to forecast the spread of a pollution cloud.

Key words: modelling the spread of air pollutans, uncontrolled waste fires, the Pasquill model

INTRODUCTION

Open burnings are defined as the combustion of materials in the environment. These include, i.e. forest fires, grass burning or waste fires in the open air. Although waste fires occur incidentally and are limited in time, in case of such incidents, there are significant amounts of pollutants released into the air, compared to burning waste in controlled conditions. This is mainly due to the reduced combustion temperature (incomplete combustion), substantially lower elevation of pollutants to the atmosphere, as well as changing climatic conditions. Therefore, in such processes there is a much greater emission of dust, carbon monoxide,

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volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs) as well as highly toxic polychlorinated dibenzodioxins and dibenzofurans [Argyropoulos et al. 2010].

Due to the various types of waste often combusted in uncontrolled conditions and difficulties in obtaining representative environmental samples for the estimation of emission factors, there is substantial uncertainty in the calculation of emissions of open combustion processes. This reflects directly the problems in estimating the actual impact of combustion on health and lives of people and the condition of the environment. Nevertheless, the scientific literature widely describes the problem of emission of pollutants into the environment from this kind of fire events, providing a wide range of emission factors depending on the type of cumbusted waste [Booher and Janke, 1997, Fingas et al., 1991, Laursen et al., 2004]. This does not change the fact, however, forecasting pollutant emissions from uncontrolled waste incineration is very difficult. As specified by Lemieux et al. [2004], open waste fires are characterised by uneven and incidental emissions from large areas, as opposed to point sources such as industrial emitters. Consequently, excessive concentrations of pollutants in the air can cause direct damage to other components of the environment, such as surface waters, land surface, fauna or flora. This is related to the deposition of pollutants at a substantial distance from the source of emission. Bearing in mind the above, it is crucial to learn the mechanisms of formation and dispersion of pollutants from uncontrolled waste fires in order to estimate their actual impact on the environment quality and human health.

The present publication describes the use of the Gaussian Dispersion Model for the plume of 1st generation with the modified input data, in order to determine the possibility of using the model to estimate the spread of pollutants in the air from uncontrolled waste fires on the example of the chemical waste fire in the village of Wszedzień, Mogilno commune.

MATERIALS AND METHODS

Operat FB was used to model the spread of pollutants in the air. The program forecasts emissions of pollutants in accordance with the methodology included in the regulation of the Minister of Environment on the reference values of specific substances in the air. The literature [Paciorek et al., 2014] states that the model described is limited in its application by means of the following:

a) the model is not sufficient for the speeds of wind under 1 m/s;
b) the possibility to use only in flat areas;
c) only passive pollutions can be modelled;
d) calculations are based on climatic windrose and atmospheric equilibrium classes, not considering the variability of the parameters in time;

e) the inability to analyse chemical changes or physical pollutions in the atmosphere.

Despite the above, the described model states the reference method of forecasting the spread of pollutants in the air in Poland, which results from the fact it is widely available and, first of all, easy to use.

Due to the above restrictions in modelling, a modified data input methodology was applied. The emission of pollutants from the chemical waste fire in Wszedzień on 28-29.05.2018 was modelled. The assumptions regarding the parameters of the windrose were modified in the beginning. For this purpose, simulated archival data based on the models of National Oceanic and Atmospheric Administration (NOAA) / National Centres for Environmental Prediction (NCEP) generated by NOAA were used. The advantage of using model data is their relation to a specific place where a fire started which substantially reduces the error margin in modelling, in comparison to data of the nearest meteorological station of the Institute of Meteorology and Water Management (IMGW). Due to the diversity of climatic conditions (directions and speeds of wind, as well as cloud cover), the fire period was divided into two sub-periods: 28-29.05.2018 and 29-30.05.2018. In the specific sub-periods, relatively uniform climatic conditions occurred. On the basis of hourly updated data, the so-called instant windroses (covering periods of 24 hours, and with 24 observations) were introduced into the program. The speeds of wind were collated considering the Pasquill stability classes, depending on the time of day, cloud cover and the speed of wind, which is necessary to calculate the diffusion coefficient [Jacyna et al., 2013]. The modification allowed to determine the real direction of the spread of pollutants during a fire.

In addition, the model assumptions were based on the description of the pollution cloud formation being a result of large-scale fires of inflammable and explosive substances [Moussa and Devarakonda, 2014] divided into four stages. The first stage is the fire and high frequency detonation. As a result of enormous energy being generated, the temperature is the highest in this phase. The second phase is the afterburn reaction. It begins just after the explosion. This is the most important stage in the synthesis of toxic substances and the rising of the cloud. Apart from local conditions affecting the speed of fumes, the main determinant is the formation of the so-called draught resulting from the temperature difference (high temperature at the bottom and low at the top), which causes a rapid elevation of the cloud. The third stage is the condensation and formation of the proper cloud. Its formation is largely determined by atmospheric factors. In this stage, the particles of dust and pollution are moved by the wind. This lasts for a few seconds, until the cloud's density equals the density of the surrounding air. The fourth stage is passive dispersion. At this stage, the cloud density stops growing, and the cloud itself is diluted and displaced. Figure 1 is a schematic depiction of the processes outlined above.

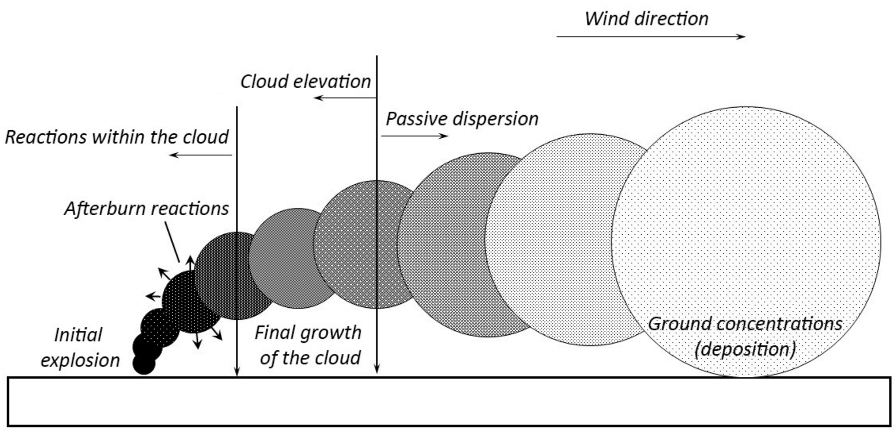

Fig. 1. Spreading of the pollution cloud based on the assumptions of the Source Characterisation Model (SCM), based on [Brown et al., 2004]

The next step was modification of the adopted emission level. Due to the fact that the model concerns only passive emission, referring to scientific reports [Bauman et al., 1996, Brown et al., 2004, Moussa and Devarakonda, 2014], the assumption was made that the passive emission in the case analysed occurred at a height of about 65 m above the ground. The height was calculated by proportion based on available audiovisual data (Photo 1). The author assumed the third phase of cloud formation takes place at this height and passive dispersion occurs. This phase can be recognised by the cloud of pollution beginning to shape horizontally, depending on the wind direction.

Pollutants released by the analysed fire dispersed over a large area. Due to the possibility of using the model in the flat area, the average roughness coefficient of 0.035 was determined, characteristic for agricultural areas dominating the landscape. The modelling was done in two variants. In variant I, the emitter height of 1.5 m was assumed (classic assumptions), in relation to the momentary windrose. In variant II (modified), the emission level of 60 m was assumed with the momentary windrose. The emission factors assumed corresponded to uncontrolled combustion of liquid fuels referred to in the literature [Booher and Janke 1997; Fingas et al., 1996].

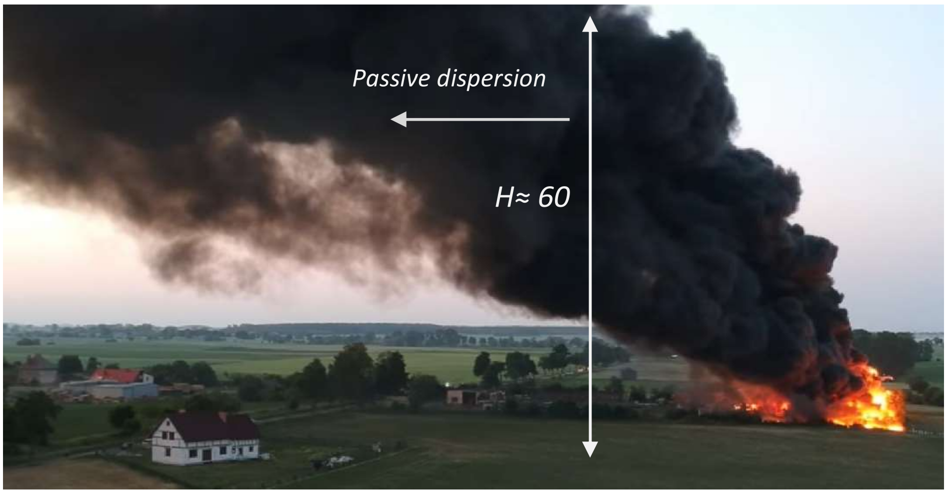

Photo 1. The shape of the pollution cloud on 28.05.2018 during the fire in Wszedzień (author: Dawid Woźniak, source: https://www.youtube.com/watch?v=d9RCNyk87gw&t=3s)

RESULTS AND DISCUSSION

Modelling results for variant I indicate the ground level concentration of pollutants decreased with the increasing distance from the emitter (Figure 2), and the highest concentration was recorded in the close proximity to the emitter (over 40,000 μg/m^3).

The concentration then fell to approx. 300 μg/m^3 at a distance of about 3 km from the emitter. It was also noted that most areas were exposed to PM10 dust concentration within the range of 100-300 μg/m^3. These results do not exactly correspond to the factual situation due to very high velocity of the gases resulting from significant temperature differences during the fire, and the passive dispersion occuring only about 60 m above the ground. Model results including modified input data indicate that the modelled direction (northwest) and shape of the dust pollution cloud corresponds to the pollution cloud system that actually occurs during the waste fire (Photos 1 and 2). The model calculations indicate that significant concentrations of dust PM10 (>300 μg/m^3) within the period of 28-29.05.2018 occurred in the close proximity to the emitter (residential area in Wszedzień) and about 3-4 km northwest of the fire location (Figure 3). Contrary to the results from the variant I calculation of PM10 concentration in the close proximity to the emitter were not this high and reached approx. 350 μg/m^3. The modelling results obtained correspond with the assumptions of Moussa and Devarakonda [2014] based on the ADORA model, which describes the shape formation of the pollution cloud and the deposition of pollutants on the ground at a further distance from the emitter.

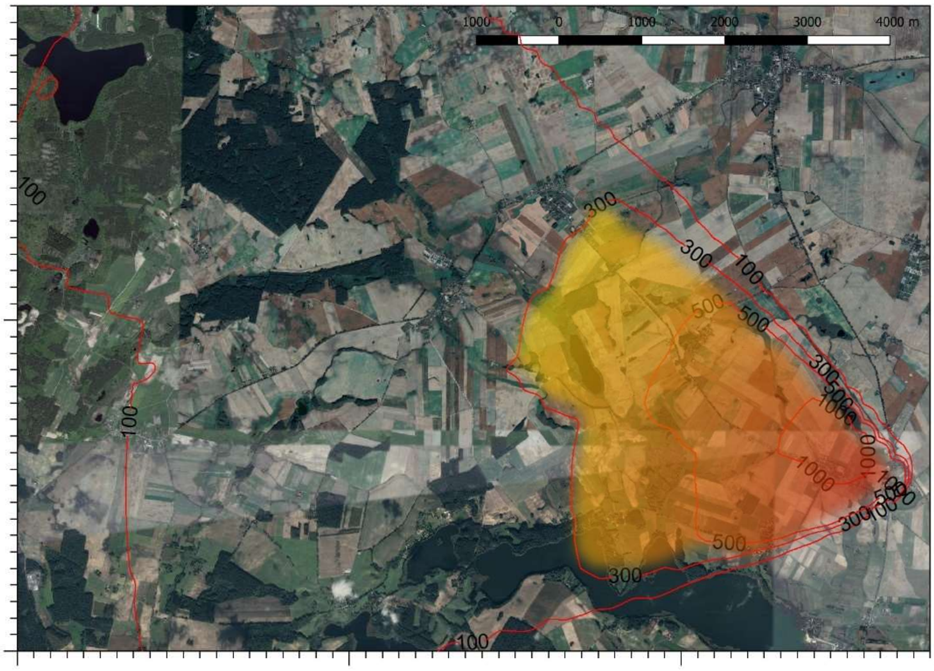

Fig. 2. Isolines of maximum concentrations of dust PM10, modelled for a fire in the period 28-29.05.2018 (variant I - emitter height: 1.5 m)

In addition, it was observed that most of the analysed area was exposed to concentrations >200 μg/m^3. The change in assumptions for modelling significantly changes the assessment parameters of the impact of pollutants emissions on the environment and human health. While the total emission of pollutants to the environment does not change, the manner they spread in the model undergoes substantial changes. The results of calculations in variant I suggest that most of the pollutants were deposited on the ground, in the close proximity to the emitter. On the other hand, the modelling in the variant II indicates that most of these substances were significantly dispersed in the air, and then deposited in a large area, whilst only a part of them was deposited in the concentration >300 μg/m^3 in a given place.

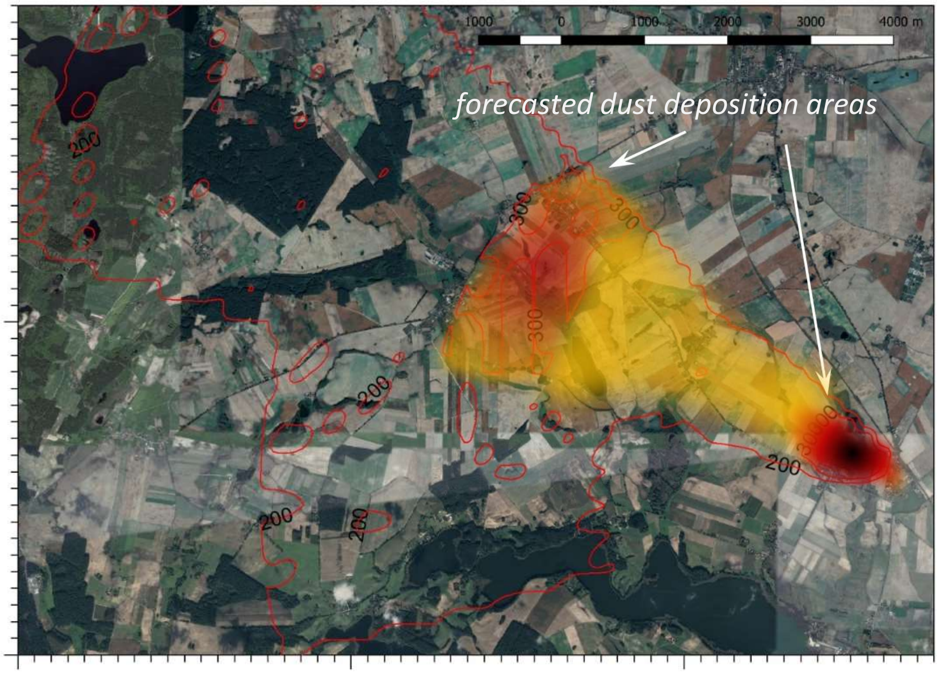

Fig. 3. Isolines of maximum concentrations of dust PM10, modelled for the fire on 28-29.05.2018 (variant II - emitter height: 60 m)

Photo 2. The shape of the pollution cloud on 28.05.2018 during the fire in Wszedzień. There is a clear decline of the pollution cloud (photo by Dawid Woźniak, source: https://www.youtube.com/watch?v=d9RCNyk87gw&t=3s)

The analysis of maximum concentrations of particulate pollutants at different altitudes (Table 1) indicates various concentration values depending on the assumed variant. In the case of variant I, the highest concentrations were recorded at the height of 0 m - this concerns the area adjacent to the emitter. The lowest calculated concentrations were found at heights 25 m and 70 m.

Tab. 1. List of maximum concentrations of dust PM10 in the receptors network at different altitudes

Altitude (m)		0	25	45	55	65	70	80
Maximum concentrations ($\mu g/m^3$)	Var. I	468	1264	5616	33663	32746	11197	3232
	Var. II	47139	1264	5616	33663	32746	1299	3232

In the case of variant II, however, the highest concentrations of PM10 were recorded at the height range of 55-65 m (>30000 $\mu g/m^3$), thus being directly related to the height of the emitter location. These concentrations are generally similar to the concentrations of dust emitted as a result of uncontrolled fires of liquid flammable substances specified in the literature [Mohan et al., 2012]. In the case of 0 m level, the highest concentration oscilated at the level of 480 $\mu g/m^3$, being also the area adjacent to the emitter.

The research conducted by the author indicates that the use of increased surface emitter's location height for a fire event increases the reliability of the results obtained. It is related to the fact that the described model is used to estimate the emission of passive pollutants, so placing the emitter only at the height, where the emission of a passive cloud of pollution occurs, seems to be the correct solution. This is consistent with the general assumptions of the model used by Moussa and Devarakonda [2014], who modelled the emission of pollutants from the fire of flammable materials. The calculations of the authors pointed out that passive emission occurs only after 55 seconds from the explosion or ignition, it results directly from the pollution cloud cooling processes. This is also confirmed by research conducted by the Brown's team [2004], where the Source Characterisation Model (SCM) was used.

Taking into account, however, the limitations of the presented model mentioned above [Paciorek et al., 2014], we need to know this model is not always applicable, and the final results are considered as calculations at the level of estimation.

CONCLUSIONS

In the case of modelling the pollution plume from incidental waste fires with the use of the Pasquill model, a modified height of the surface emitter should be used (depending on the size of the fire), as well as the momentary windrose with as many observations as possible. The research indicates that the model can be used for short fire periods (maximum 24 hours), with similar meteorological conditions determining the atmospheric stability class (similar speed and direction of winds, the same degree of sun exposure or cloud cover, no precipitation). Moreover, contrary to the limitations of the model concerning the modelling possibilities in flat area, due to the high altitude and large dispersion area, the terrain shape and land use do not substantially affect the modelling results. This does not apply to large water reservoirs, which significantly change the air humidity, or orographic barriers, such as mountain ranges. It has to be taken into consideration, however, that the model does not account for the possibility to analyse the chemical changes or physical pollution in the atmosphere. Therefore, the use of the model is not recommended in case of changing weather conditions. In addition, it is advisable to continue research in this field, first of all taking into account the verification of the author's assumptions, using more advanced models of the Gaussian formula for the plume of 2nd or 3rd generation.

Taking the above into account, the model studies conducted by the author of the publication indicate the applicability of a simple model using the Pasquill advection-diffusion equation to forecast and estimate the pollution dispersion from incidental waste fires, taking into consideration the limitations mentioned above.

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