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AIR QUALITY INFLUENCE OF SELECTED POLLUTANTS EMITTED FROM A FIRE OF 300 MG OF MUNICIPAL WASTE ON AMBIENT AIR QUALITY: AN EXAMPLE OF MODELLING WITH HYSPLIT

Abstract

Reducing the amount of waste disposed of in landfills requires treatment in specialised facilities. Potential threats that can arise both in waste processing and in its storage comprise a fire hazard. Waste fires hold a significant share of the total number of the largest fires in Poland. Fires in landfills and their treatment facilities are related to air quality since during a fire a large number of various pollutants is emitted into the atmosphere in a relatively short time. The paper discusses the impact of a fire taking place at a waste treatment facility on air quality, in which 300 Mg of municipal waste was burnt. Using the HYSPLIT package, the atmospheric dispersion of 23 selected organic and inorganic pollutants was determined and then analysed in GIS software. The concentrations were compared with reference values specified in relevant legal regulations. Of the 23 substances analyzed, the concentration levels were exceeded only for 6 substances at a distance of more than half a kilometre from the fire: benzo(a)pyrene, benzene, styrene, acetaldehyde, PM_{10}, and NO_2. The substance with the greatest range as regards the reference concentration levels was benzo(a)pyrene, a compound with a proven carcinogenic effect, which indicates the importance of reducing landfill fires in the context of public health.

Keywords: waste fire, environmental impact, exposure to pollutant, atmospheric dispersion, HYSPLIT, fire risk, rescue management

WPŁYW WYBRANYCH ZANIECZYSZCZEŃ POWIETRZA WYEMITOWANYCH W POŻARZE 300 MG ODPADÓW NA JAKOŚĆ POWIETRZA ATMOSFERYCZNEGO – PRZYKŁAD WYKORZYSTANIA HYSPLIT

Abstrakt

Zmniejszenie ilości odpadów składowanych na wysypiskach wymaga ich przetwarzania w wyspecjalizowanych zakładach. Wśród zagrożeń, które pojawiają się zarówno w przetwarzaniu odpadów, jak i ich składowaniu, znajduje się zagrożenie pożarowe. Pożary odpadów mają znaczący udział w ogólnej liczbie największych pożarów w Polsce. Podczas pożaru duża liczba różnych zanieczyszczeń jest emitowana do atmosfery w stosunkowo krótkim czasie, w związku z czym pożary odpadów są związane z jakością powietrza atmosferycznego. W pracy omówiono wpływ pożaru w zakładzie przetwarzania odpadów na jakość powietrza, w którym spłonęło 300 Mg odpadów komunalnych. Przy wykorzystaniu pakietu HYSPLIT wyznaczono dyspersję atmosferyczną 23 wybranych zanieczyszczeń organicznych i nieorganicznych, a następnie przeanalizowano ją w oprogramowaniu GIS. Stężenia porównano z wartościami referencyjnymi określonymi w odpowiednich aktach prawnych. Spośród 23 analizowanych substancji poziomy odniesienia zostały przekroczone tylko dla 6 substancji w odległości ponad pół kilometra od ognia: benzo(a)pirenu, benzenu, styrenu, aldehydu octowego, PM_{10} i NO_2. Substancją o największym zakresie, jeśli chodzi o poziomy stężeń referencyjnych, był benzo(a)piren, związek o udowodnionym działaniu rakotwórczym, co wskazuje na znaczenie ograniczenia pożarów składowisk w kontekście zdrowia publicznego.

Słowa kluczowe: pożary odpadów, oddziaływanie na środowisko, ekspozycja na zanieczyszczenia, rozprzestrzenianie atmosferyczne, HYSPLIT, ryzyko pożarowe, zarządzanie akcją ratowniczą

1. Introduction

Changes in the global economic system which took place after February 2022 underlined the importance of some industries. The scarcity of fossil fuels has compelled us to focus on alternative ways of their obtaining. One of the quickly developing branches is the production of RDF (refuse-derived fuel). RDF is one of the most promising ways of waste disposal owing to the simultaneous solving of the problem of solid waste disposal and lack of fuel. The gross calorific value (GCV) of these fuels varies depending on the composition, and typically is in the range of 17-21 MJ/kg, while RDFs with higher GCV are also produced [1–3]. Therefore, RDF should be an increasingly desirable fuel. On the one hand, its GCV is much greater than that of wood and even close to the GCV of hard coal [4]. However its production is associated with the management of waste that is often difficult to use otherwise (e.g. municipal waste). This may be even more important in the future due to the announced energy crisis.

The increase in RDF production causes also an increase in fire risks since bigger amounts of waste have to be stored to fulfil the market demand for fuel. One of the recent examples of fires involving RDF was a fire at the RDF production facility in Osła, Poland [5] in which, in the storage yard, there were 10 Gg of plastics and

1.2 Gg of RDF. The extinguishing of this fire involved over 200 firefighters, 74 fire engines, an unmanned aerial vehicle and special rescue units. Such fires can become more frequent in the future, even though fire safety of waste storage in Poland is the object of strong law regulations. The existing equipment with air quality measurement accessories, both for sanitary services in Poland and the State Fire Service, is insufficient to allow making a precise assessment of the environmental risk in such a fire. The currently used equipment allows only the detection of the majority of the emitted compounds without the possibility of establishing more or less precisely their amount in the air. There is a need of developing procedures that could quickly evaluate the possible dispersion. The previous research shows that the most common place of waste fires is next to the residential areas [6]. Hence, it is important to support the rescue operation with reliable data about the atmospheric dispersion of burning products. It would help make decisions whether evacuation of people or other actions are required during the rescue. In order for these procedures to be used to analyze the environmental effects of each subsequent event, they must be based on actual data and information, including among others:

- meteorological conditions during the fire and throughout the period of forecasting subsequent consequences;
- amount and type of burnt materials/stored waste/processed waste;
- topographic conditions;
- land farm, including the distance from housing or critical facilities such as nursing homes, kindergartens, schools, etc.

The article shows how the risk to air quality during a major fire at a municipal waste treatment plant can be assessed practically, but without the use of measuring equipment. The proposed methodology can be used during a fire since results may be obtained in only a few minutes. Moreover, the application of the presented methodology practically does not entail any costs. The presented model of dispersion calculation can be used for each type of fire, especially when the burning material has a known composition (and consequently appropriate emission factors during a fire can be selected). It can be also used to evaluate the impact of historical fire events including the assessment of actions taken by crisis management services.

2. Materials and methods

In the work, emission from accidental combustion of 300 Mg of municipal waste is evaluated. Accidental combustion of waste can be treated as open burning hence the emission factors for open burning of waste can be used to estimate the total amount of pollutants emitted to the atmosphere. The total emission of substances during the fire was determined according to the simplified formula from [7]:

$$EM_x = M \cdot EF_x \quad (1)$$

where:

- EM_x is the total emission of substance x in the fire,
- M is the mass of the municipal waste, in the case at hand $M = 300$ Mg,
- EF_x is the emission factor of substance x during open burning of waste.

Emission factors for open waste burning are presented in [7–11], on the other hand, reference levels of concentrations of some substances in atmospheric air are defined by law applicable in Poland [12]. Consequently, the work focuses on 23 organic and inorganic substances from [12] for which emission factors are known from [7–11], i.e.: Acetaldehyde, Acetone, Acrolein, Benzene, Benzo[a]pyrene, Bis(2-ethylhexyl)phthalate, Chlorophenol, Chlorobenzene, CO, Cresol, Di-n-butylphthalate, Ethylbenzene, Fluorine, Formaldehyde, HCl, Methylenechloride, NO_x, Phenol, particulate matter PM_{10}, SO_2, Styrene, Toluene, Xylene (Table 1).

Tab. 1. List of substances analyzed in this work with their CAS number, emission factors, and the reference value of 1-h average concentrations

Substance	CAS	Emission factor kg/Mg	The reference value of 1-h average concentration µg/m³
Acetaldehyde	75-07-0	0.4284	20
Acetone	67-64-1	0.25375	350
Acrolein	107-02-8	0.02665	10
Benzene	71-43-2	0.97975	30
Benzo(a)pyrene	50-32-8	0.0014	0.012
Bis(2-ethylhexyl) phthalate	117-81-7	0.02379	100
Chlorophenol	25167-80-0	0.019	20
Chlorobenzene	108-90-7	0.00074	100
Carbon monoxide	630-08-0	42.38	30000
Cresol	1319-77-3	0.06877	30
Di-n-butylphthalate	84-74-2	0.00345	100
Ethylbenzene	100-41-4	0.18175	500
Fluorine	7782-41-4	0.00299	30
Formaldehyde	50-00-0	0.44365	50
Hydrogen chloride	7647-01-0	2.4	200
Methylene chloride	75-09-2	0.017	200
NO_x	11104-93-1	3.09	200
Phenol	108-95-2	0.11266	20
PM_{10}	-	4.51	280

Substance	CAS	Emission factor kg/Mg	The reference value of 1-h average concentration μg/m³
Sulphur dioxide	7446-09-5	0.5	350
Styrene	100-42-5	0.5275	20
Toluene	108-88-3	0.372	100
Xylene	1330-20-7	0.038	100

Source: own study based on [7–12]

Emissions evaluated in this way were used as masses input to the HYSPLIT model [13]. The dispersion was calculated using methodology from [14,15]. The HYSPLIT is capable of using different sources of meteorological data. Given the expected ranges of transport, the GFS 0.25 deg were used [16]. Since the precise time course of the fire is not known, emission during the fire is assumed to be constant and lasted 24 hours. The dispersion was calculated 48 hours after the fire has begun. The simulation also assumed that release takes place at the ground level. For each hour after the outbreak of the fire the spatial distribution of average 1-h concentration of pollutant was determined. The output of the HYSPLIT was transformed to vector shapefile, which can be processed in any Geographic Information System software. In this work, QGIS 3.22 Białowieża was used [17]. Polygons where the concentration of a given pollutant was exceeding the reference level were drawn on the map. Next, the polygons from every hour were dissolved in order to determine the region, where the 1-h reference concentration was exceeded for at least one hour. Two critical factors of impact of this fire, according to [14], were determined, and namely:

- the area where the concentration was exceeding the reference value;
- the distance to the furthest point where the concentration was exceeding the reference value.

The whole procedure was repeated for every pollutant. Moreover, for the pollutant found to have the highest critical factors, a determination was made of the exposure duration, i.e., for every point in a 10mx10m grid the duration of exposure for concentrations higher than reference values was determined.

3. Results and discussion

The masses of substances emitted into the atmosphere are presented in Table 2. The emitted mass influences the maximum 1-h average concentration. The highest concentration was observed 230 m away from the fire location. At this point, the highest ratio of simulated concentration to reference level was observed for benzo(a) pyrene and exceeded 10 000% of the reference level. Although the maximum benzo(a)pyrene concentration is very high, the area where the reference value was exceeded for up to 6 hours is 400 ha, up to 12 hours is 95 ha, and up to 18 hours it is 5 ha, hence the influence on the excess carcinogenic risk [18] of this fire is limited (Figure 1). The second substance is benzene whose concentration exceeded 2700% of the reference value. Benzene is found to be one of the compounds whose increase in concentration indicates that a fire has an impact on air quality [19]. The third substance, with a concentration exceeding 2200% of the reference value, is styrene, which is one of the main sources of the combustion of its polymers like polystyrene [20, 21]. The maximum observed concentration of acetaldehyde was of the order of 1800%. One of the possible sources of acetaldehyde in the air is incomplete wood burning [22].

Tab. 2. Masses *M* of substances emitted in a fire 300 Mg of waste, maximum 1-h average concentrations C_{1h} and the critical parameters of regions where concentrations were exceeding levels for at least 1 h: area *A* and distance to the farthest point from the fire site *d*

Pollutant	*M* (kg)	C_{1h} (µg/m³)	*A*(ha)	*d*(m)
Acetaldehyde	128.52	360	28	940
Acetone	76.125	210	<0.005	<200
Acrolein	7.995	22	1.1	430
Benzene	293.925	830	46	1277
Benzo[a]pyrene	0.42	1.2	400	3770
Bis(2-ethylhexyl) phthalate	7.137	20	<0.005	<200
Chlorophenol	5.7	16	<0.005	<200
Clorobenzene	0.222	0.62	<0.005	<200
CO	12714	36000	0.0054	<200
Cresol	20.631	58	0.30	400
Di-n-butylphthalate	1.035	2.9	<0.005	<200
Ethylbenzene	54.525	150	<0.005	<200
Fluorine	0.897	2.5	<0.005	<200
Formaldehyde	133.095	370	7.8	470
HCl	720	2000	8.2	470
Methylene chloride	5.1	14	<0.005	<200
NO2	927	2600	13	730
Phenol	33.798	95	7.2	460
PM10	1353	3800	14	770
SO2	150	420	0.0070	<200

Pollutant	*M* (kg)	C_{1h} (μg/m³)	*A*(ha)	*d*(m)
Styrene	158.25	440	35	970
Toluene	111.6	310	5.5	450
Xylene	11.4	32	<0.005	<200

Source: own study

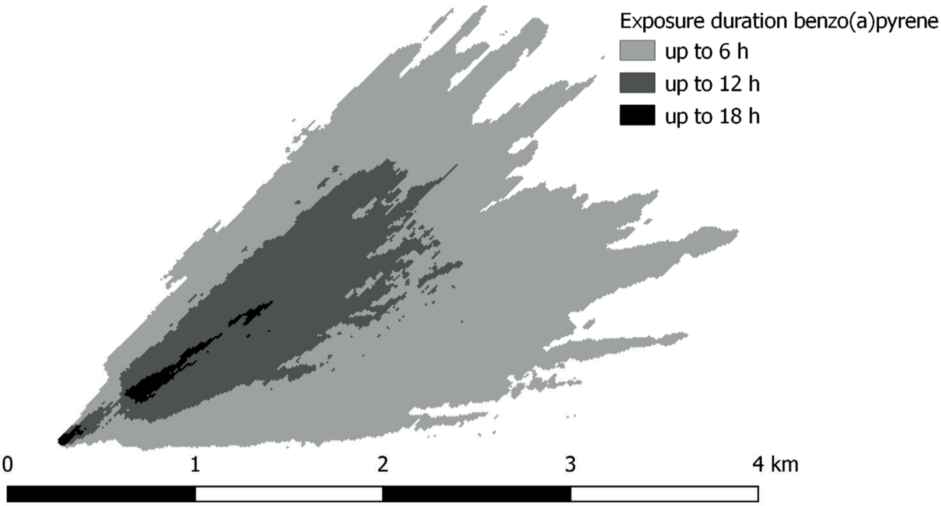

Fig. 1. Duration of excess of reference level concentration for benzo(a)pyrene.
Source: own study

Particulate matter (PM) is a generic material for every combustion process. In the discussed fire the maximum concentration exceeded 1300% of the reference value. The next substance with similar excess of reference level concentration is nitrogen dioxide. One of the sources is unvented burning in stoves [23].

Over 70% of global hydrogen chloride atmospheric emission is caused by solid waste incineration and biomass burning [24], hence it is not surprising that the waste fire give rise to significant concentrations of these substances (maximum concentration of 1000% of the reference value).

The maximum observed 1-h average concentration of remaining substances was not exceeding 1000% of their respective reference levels and were 740% of appropriate respective reference levels for formaldehyde, 480% for phenol, 310% for toluene, 220% for acrolein, 190% for cresol, and 120% for carbon monoxide and sulphur dioxide. The maximum evaluated concentration of the remaining substances did not exceed the reference level mentioned in the relevant regulations [12]. Among the major sources of formaldehyde, incinerators are listed [25].

Toluene, similarly to benzene, has proven to be one practical indicator of the impact of fire on air quality [19]. Burning organic matter is one of the main sources of acrolein in the atmosphere [26]. Combustion of municipal solid waste produces cresols [27], hence the significant increase in cresol concentration from this fire is justified. Carbon monoxide is produced in incomplete combustion, as it can be in the case of open burning with limited air (oxygen), while sulphur dioxide is a typical pollutant produced during combustion, for example plastics [7].

The dissolved polygons of dispersion of substances are presented in Figure 2. The range of excess of all substances was less than 4 km, while only for six substances, benzo[a]pyrene, benzene, styrene, acetaldehyde, PM_{10}, and NO_2 the range exceeded half a kilometre. The pollutants disperse in a cone of an angle of ca. 45° and areas with a concentration increase do not exceed 50 ha, except for benzo[a]pyrene, for which it amounts to 400 ha.

Fig. 2. Map of dispersion of substances with an impact range larger than 500 m emitted during a fire of 300 Mg municipal waste.

Source: own study

Such results indicate that emissions from potential accidents in such facilities have a limited area of impact. The location of RDF factories should be adjusted according to the possible amount of stored waste, as in the discussed case, no less than 500 m. Perfect areas for such a facility comprise post-industrial zones, as well as special economic areas distanced from residential housing. In the case of the Osła fire mentioned in the introduction, the distance to the nearest housing was around 1 km.

4. Conclusion

The paper presents a practical application of a methodology for assessing the impact of fire on air quality as expressed by the increase in concentrations of selected pollutants in ambient air. It focuses on the fire of 300 Mg of municipal waste and the application of previously developed methodology based on the atmospheric dispersion of puffs.

The obtained results allowed determining the intensity and range of the impact that a fire could have on air quality in the vicinity of the facility. It was shown that such fire has a significant impact on the concentration of the majority of investigated pollutants. The reference level of 1-h average concentration of benzo(a)pyrene was found to have been exceeded 100 times. Although the intensity (increase in concentration) is high, the range of impact is low since this concentration could be observed at a distance of 200 m from the fire. The range of impact was always less than 4 km while only for 6 substances it was more than 500 m.

These results should be used as part of a new basis for the choice of the location of newly created waste-related facilities. The decision for the allocation of such facility should include not only the potential risk of accidents, like for example of a fire, but also a complex assessment of their environmental impact (in case of a fire – atmospheric dispersion of products). The fire risk at such facilities cannot be eliminated and fire incidents will still continue happening in the future. The procedure of EIA (environmental impact assessment) should also include an analysis of the environmental fire impact for projects with increased fire risks, such as waste treatment facilities. The simulation of an impact of a fire on atmospheric air based on the amount of stored waste, its composition, and the estimated ranges of real impact (HYSPLIT simulation) should be incorporated in the EIA report, or could be omitted if the facility is situated in special economic zones, post-industrial locations without residential housing in direct range. This part of the EIA procedure would make it possible to determine in a precise, scientific way where facilities storing, for example, waste should be allocated in order to minimise the impact on the health and comfort of people living in the neighbourhood.

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