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MODELING OF POLLUTANTS IN THE AIR IN TERMS OF FIRE ON DUMPS

MODELOWANIE ZANIECZYSZCZEŃ POWIETRZA W WARUNKACH POŻARU NA WYSYPISKU

Abstract: Paper presents modelling of pollutants in the air in terms of fire on dumps. Uncontrolled fire on dumps where are tyre produce a lot of smoke and air pollutants, including benzene and polycyclic aromatic hydrocarbons (PAH). Great heat leads to the generation of pyrolytic oil which, when mixed with the fire extinguishing agent, contaminates the surrounding soil, surface water and underground water. Paper analyzes and presents in particular the emission factors of incomplete burning of waste car tyres. Metal dust emissions have been presented as well as volatile organic compund (VOC) emissions, slightly volatile organic compound (SVOC) emissions and emissions of polycyclic aromatic hydrocarbons (PAH). Evaluation of the effect on the air quality has been graphically presented by modelling of uncotrolled tyre burning by using EPA "SCREEN 3 MODEL".

Keywords: pollutants, modeling of pollutants, fire, dump

Dumps are a major problem in Serbia since the fires comes the emergence of a large number of pollutants that may adversely affect the living and working environment. Waste tires are disposed of in many countries landfills, a practice that in developed countries quickly abandoned, and in many countries the law restricted or prohibited it [1].

Tires are a mixture consisting of vulcanized or cross-linked polymers, carbon black, dispersed oil, sulphur, synthetic fibres, pigments, chemical additives and steel or fibreglass. Tire manufacturers use various formulation recipes for the production (Table 1). Tire is a very flammable material. It may lead to spontaneous exothermic pyrolysis reactions with the development of inflammatory gases, and their burning [2].

Fire, particularly in landfills where the waste tires they usually are in large numbers, is a serious accident due to the specific behavior of burning rubber and very toxic (carcinogenic and mutagenic even) products of the combustion. This fire is very difficult to extinguish [1].

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Even when densely packed, there could be sufficient oxygen to make burning possible. Tire fires are most frequently started as deliberate, malicious acts, and they produce a great amount of heat, due to which it is very difficult to access the fire and extinguish it. The released heat energy from tire burning is extremely high 37600 kJ kg^{-1} compared with coal, which is 27200 kJ kg^{-1}.

There are examples of some tire fires that lasted for months, even in the developed countries that have the means and equipment to put them out. For instance, the Rhinehart car tire fire in Winchester, Virginia, USA lasted almost nine months and the smoke plume was 100 m high and spread 80 km, causing pollution in three states [3]. This uncontrolled tire fire produced a lot of smoke and toxic air pollutants, including benzene and *polycyclic aromatic hydrocarbons* (PAH). Great heat causes the generation of pyrolytic oil which, when mixed with the fire extinguishing agent, contaminates the surrounding soil, surface water and groundwater.

Tire fires may vary and pollutant concentrations cannot be accurately predicted. There are many factors influencing the emissions generated in fires. Some of these factors depend on the fuel quantity, flame temperature, meteorological conditions, area topography, etc. Most frequently in the wind direction, the following are determined: VOC (*volatile organic compounds*) concentrations, SVOC (*semi-volatile organic compounds*), including PAH (*polycyclic aromatic hydrocarbons*), carbon monoxide, and *particulate matter* (PM) which includes metals.

Table 1

Typical composition of tires for the motor vehicles

Material	**Content [%]**
Styrene butadiene	46.78
Carbon black	45.49
Aromatic oil	1.74
Zinc oxide	1.40
Stearic acid	0.94
Antioxidant 6C	1.40
Wax	0.23
Sulphur	1.17
Accelerator CZ	0.75

Emission factors of products of incomplete combustion

In our country, there had been no thorough researches that deal with this extremely important environmental issue of incomplete waste combustion, due to which we had to refer to foreign literature. In this manner, we are also drawing attention to the necessity of an urgent introduction of waste treatment without burning, and particularly to the catastrophic environmental consequences that uncontrolled and frequent waste burning at illegal and other dumping places may have.

In literature documents [4-7] have been published two papers about emission factors for incomplete combustion of waste that includes waste tires as well.

The basis for the determination of the stated emission factors is the paper used by US EPA, 1989 (EPA-600/2-89-054) [8]. For PM particle matter (mostly metals and soot), public literature offers numerous emission data that range from about 119 grams per 1 kg of incompletely combusted tire emission [9] US EPA, October 1989 (EPA-600/2-89-054, NTIS PB90-126004) to carbon monoxide CO emission estimated at 122.8 g kg^{-1} of burnt tire. Data from the literature are presented in a more detailed way in the following Tables 2 and 3:

Table 2

Metal dust emission during car tire burning

Pollutant	**[mg kg^{-1} of tire]**	**Pollutant**	**[mg kg^{-1} of tire]**
Aluminium	3.07	Iron	11.8
Antimony	2.94	Lead	0.34
Arsenic	0.05	Magnesium	1.04
Barium	1.46	Nickel	2.37
Calcium	7.15	Selenium	0.06
Chromium	1.97	Silicon	41.0
Copper	0.31	Sodium	7.68
TOTAL	81.24		

Table 3

Emissions of VOC and SVOC during uncontrolled car tire burning

Class	**Compound**	**Emission [mg · kg^{-1}]**	**Compound**	**Emission [mg · kg^{-1}]**
VOCs SVOCs	Benzaldehyde	314.4	Ethynylbenzene	160.75
	Benzene	2180.5	Ethynyl,methylbenzene	394.65
	Benzodiazine	15.55	Isocyanobenzene	318.55
	Benzofuran	12.55	Limonene	460.0
	Benzothiophene	20.5	Toluene	1367.7
	Butadiene	234.6	Methylindene	228.25
	Dihydroindene	41.7	Methylthiophene	9.05
	Xylenes	928.95	Methyl,ethenylbenzene	66.15
	Dimethylhexadiene	59.6	Methyl,methylethenylbenzene	390.75
	Dimethyl,methylpropyl benzene	7.45	Methyl,methylethylbenzene	197.45
	Dimethyldihydroindene	19.85	Methyl,propylbenzene	20.8
	Ethenylbenzene	776.6	Ethyleneindene	41.45
	Ethenylcyclohexene	66.90	Methylethylbenzene	152.15
	Ethenyl,dimethylbenzene	15.45	Propylbenzene	78.3
	Ethenyl,methylbenzene	16.8	Styrene	652.7
	Ethenyldimethylcyclohexene	175.2	Tetramethylbenzene	127.85
	Ethenylmethylbenzene	131.25	Thiophene	41.25
	Ethylbenzene	377.95	Trimethylbenzene	60.90
	Ethyl,methylbenzene	405.15	TOTAL	10569.7
	1-Methylnaphthalene	279.15	Ethyl,dimethylbenzene	136.2
	1,10-Dimethylbiphenyl, methyl	5.55	Hexahydroazepinone	411.8
	2-Methylnaphthalene	389.95	Indene	421.3
	Benzoisothiazole	86.95	Isocyanonaphthalene	4.7
	Benzo[b]thiophene	22.1	Methylbenzaldehyde	43.3
	Biphenyl	269.8	Phenol	533.05
	Cyanobenzene	370.25	Propenylnaphthalene	11.75
	Dimethylbenzene	620.05	Propenyl,methylbenzene	261.8
	Dimethylnaphthalene	109.6	Trimethylnaphthalene	157.9
	TOTAL			4135.2

Additional researches have been conducted and published [10] from which we are presenting the following emission factors of a certain toxic matter separately in mg per kg of burnt tire (Table 3) are shown in Table 4.

As it can be seen in the tables above, emitted quantities of toxic matter depend on the quantity of burnt tire. Based on the existing experience, we believe that a burning tire heap is practically impossible to put out. Emission analysis of the products of waste or recycled tire burning, if they are in one heap, would show environmentally unacceptable results [11].

Table 4

Polycyclic aromatic hydrocarbon (PAH) emissions during uncontrolled car tire burning

Class	Compound	Emission [mg · kg^{-1}]	Compound	Emission [mg · kg^{-1}]
PAHs	Naphthalene	650.95	Benz[a]anthracene	92.3
	Acenaphthylene	711.55	Chrysene	81.2
	Acenaphthene	1368	Benzo[b]fluoranthene	78.9
	Fluorene	223.65	Benzo[k]fluoranthene	86.85
	Phenanthrene	245	Benzo[a]pyrene	99.35
	Anthracene	52.95	Dibenz[a,h]anthracene	0.55
	Fluoranthene	398.35	Benzo[g,h,i]perylene	112.7
	Pyrene	92.75	Indeno[1,2,3-cd]pyrene	68.55
	TOTAL			4363.6

That is why additional protection measures have to be taken, that the tires are disposed in smaller heaps, which are sufficiently distanced from one another, but also with a limited height, so that transfer of fire from one heap to another would not occur. Table 5 presents the example of minimum distance between the heaps disposed in a safe manner, not permitting fire transfer.

Table 5

Minimum distance between tire heaps disposed in a safe manner

Length of opposite sides [m]	Height of disposed tires [m]						
	2.4	**3**	**3.7**	**4.3**	**4.9**	**5.5**	**5.5**
7.6	17.1	18.9	20.4	22.3	23.5	25	25.9
15.2	22.9	25.6	28.3	30.5	32.6	34.4	36
30.5	30.5	35.4	39	41.8	44.5	47.2	50
45.7	30.5	35.4	39	41.8	44.5	47.2	50
61	30.5	35.4	39	41.8	44.5	47.2	50
76.5	30.5	35.4	39	41.8	44.5	47.2	50

These minimum distances depend on the height and dimensions of the heap [5]. Considering the vicinity of the neighbouring factories and settlements, we believe that the most favourable distance between the disposed tire heaps is 17.1 m, the maximum disposed tire heap height 2.4 m, and the maximum length of the opposite sides of the dumping area 7.6 m. In that case, about 10 Mg (tons) of tire could be burnt in one heap (7.6 m x 10 m), leading to emissions stated in the Table 5 [12]. It has been estimated that the burning of a 10 Mg (tons) tire heap would last about 24 h, based on which emission in [g s^{-1}] has been calculated, which is a necessary input for the calculation of matter dispersion through air.

For the calculation of dispersion of suspended matter with the most unfavourable conditions and vertical stability 6 (G) and wind velocity of about 1 m s^{-1}, EPA "SCREEN3 MODEL" Scenario 1.2. referring to surface emissions.

Methodology

Pollutant dispersion has been determined per Gaussian puffs and plume model for immediate sources:

$$C(x,y,z) = \frac{q}{\sqrt[3]{2\pi\sigma_x\sigma_y\sigma_z}} \exp\left\{-\left[\frac{(x-ut)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2}\right]\right\} \times \left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} \tag{1}$$

Pollutant dispersion has been determined per Gaussian puffs and plume model for sources (routine emission):

$$C(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z\, u} \exp\left(\frac{-1}{2}\frac{y^2}{\sigma_y^2}\right)\left\{\exp\left[\frac{-1}{2}\frac{(z-H)^2}{\sigma_z^2}\right] + \exp\left[\frac{-1}{2}\frac{(z+H)^2}{\sigma_z^2}\right]\right\} \tag{2}$$

Equation (1) is used for calculating the pollutant concentration at the time of not controlled burning, while equation (2) is used for calculating the pollutant concentration at the time of controlled burning [13].

Discussion of results

This methodology presents the application of EPA "SCREEN3 MODEL" for the dispersion of toxic pollutants that are generated during the uncontrolled burning of automobile tires that can occur due to improper tire storage. These results provide the evaluation of time and concentration of pollutant dispersion in the local atmosphere.

Table 6

Table of calculated concentrations of CO, PM and PAH ("worst case")

Distance [m]	**CO [mg · m^{-3}]**	**PM [mg · m^{-3}]**	**PAH [mg · m^{-3}]**
100	5952.0	5760.0	209.50
200	2642.0	2557.0	92.980
300	1488.0	1440.0	52.370
400	959.30	928.30	33.760
500	674.00	652.30	23.720

Results

The results have been presented on the map of the town of Kovin, showing that the ground concentrations of carbon monoxide and suspended matter in the Industrial zone are average 1000 and 2500 mg m^{-3}, respectively, which can be considered a catastrophic situation, considering that these values significantly exceed the prescribed concentration limit values for CO and PM of 5 and 0.12 mg m^{-3}, respectively (Figs. 1 and 2). In the residential area, CO and PM concentrations model for the most unfavourable conditions, can exceed 500 mg m^{-3} during tire burning.

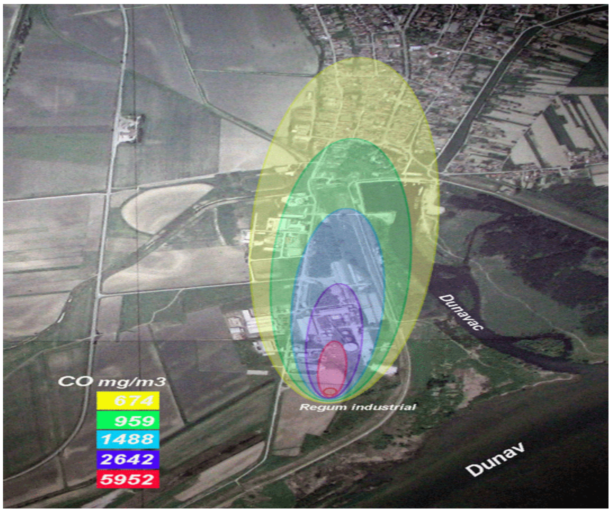

Fig. 1. Graphical representation modelling for pollutant CO

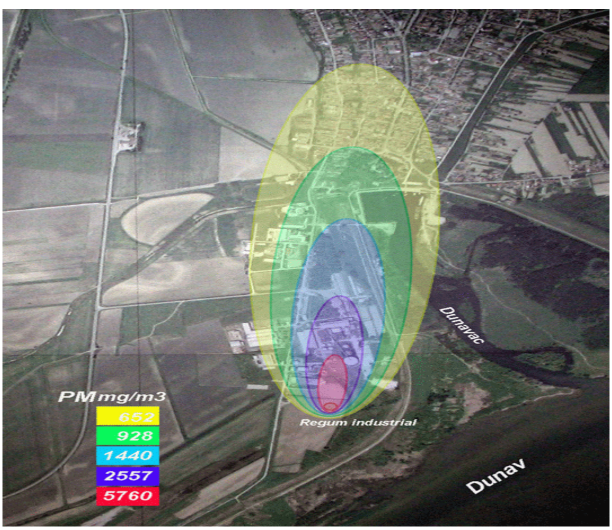

Fig. 2. Graphical representation modelling for pollutant PM

Disposal of the waste tires on the legal and illegal landfills is not damaging the environment all by itself, but such landfills could cause great air, soil and underground water pollution should they burn and they would cause great damage subsequently [14]. Relative to the overall viability, it is most recommendable to process (retread) used tires and reuse them for their initial purpose. For the freight vehicles program in most developed countries used tires are retreaded and only after several retreading they are discarded as waste tires, and in transport vehicles, due to the different components of tires and greater moving velocities, such process is not possible.

Waste tires (entirely) have limited use and in limited areas, whereas recycling of waste tires produces raw materials and products that have appliance in construction and rubber products production, in production of steal, etc, which boost the market of rubber recycling products.

The use of waste tires as a fuel is ecologically more acceptable than the use of traditional fossil fuels because a pneumatic tire uses 30% of natural rubber, which is renewable energy source, and its chemical compounds do not pollute the environment more than fossil fuels while burning in controlled conditions [17].

Waste tires (entire or cut) are used as safe, alternative fuel in cement factories and as basic fuel in thermal power plants. Due to agreeable economical effect the demand of the cement factories for the waste tires as additional fuel continues to grow and the amounts of rubber which cement factories could spend are virtually limitless [18].

Conclusions

Based on the presented calculated values of polycyclic aromatic hydrocarbons (PAH) in the range from 23.79 to 216.10 mg m^{-3}, it can be concluded that it is necessary to take very comprehensive and stringent measures that guarantee that burning of tires will not occur, and in case it does happen, fire has to be localized and extinguished as soon as possible, since otherwise, it may have catastrophic consequences on the life and health of the factory workers, the population, as well as the environment.

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MODELOWANIE ZANIECZYSZCZEŃ POWIETRZA W WARUNKACH POŻARU NA WYSYPISKU

Abstrakt: Przedstawiono modelowanie zanieczyszczeń powietrza w warunkach pożaru na składowisku. Niekontrolowany ogień na składowiskach opon powoduje powstawanie dymu i zanieczyszczeń powietrza, w tym benzenu i wielopierścieniowych węglowodorów aromatycznych (WWA). Wydzielane ciepło prowadzi do generacji oleju pirolitycznego, który po zmieszaniu ze środkami gaśniczymi zanieczyszcza glebę, wody powierzchniowe i gruntowe. W pracy przeanalizowano i przedstawiono zanieczyszczenia emitowane w wyniku niepełnego spalania opon samochodowych. Stwierdzono emisję pyłów metali, lotnych związków organicznych (VOC), mało lotnych związków organicznych (SVOC) oraz wielopierścieniowych węglowodorów aromatycznych. Ocena wpływu spalania opon na jakość powietrza została graficznie przedstawiona za pomocą modelu EPA „SCREEN 3 MODEL”.

Słowa kluczowe: zanieczyszczenia, modelowanie zanieczyszczeń powietrza, pożar, składowisko