ASSESSMENT OF AIR EMISSIONS ASSOCIATED WITH ASPHALT PAVING

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***ABSTRACT**: Development of road infrastructure together with the rising number of cars has led to an increase in the number of asphalt plants. Asphalt is made of different types of mineral aggregates and bitumen, the latter being obtained from petroleum refineries residues. As they are not combustion emissions, air emissions generated by asphalt paving are usually neglected, being not considered major sources of emission. Miscellaneous research studies conducted in the last years have shown that this type of emissions is quite significant, as it continues to exist long after the road was paved, with increased values during hot weather. This study estimated the emissions resulted from the pavement of a street located in Alba Iulia city, Romania, from asphalt production to road paving and even after construction works were finished. The study was conducted using the emission estimation methods approved in Romania. Also, the research covered the emissions resulted from aggregates storage and those coming from the exhausting pipes of the equipment operated inside the asphalt plant.*

***Keywords**: asphalt; air emissions; pollutants.*

1. Introduction

Romanian road infrastructure is situated on the bottom of the list in Europe, as far as both number of kilometers of highways and infrastructure wear are concerned. This fact is associated with reduced average transport speed on public roads and leads to an increase in air polluting emissions.

The development of infrastructure by construction of highways and express roads has both positive and negative effects on all environmental factors. Among the positive effects of infrastructure development, there are: traffic fluidization and decongestion, increased travel speed and shortened travel time, less accelerations and decelerations and hence lower fuel consumption, less car accidents and increased road safety, less air polluting emissions [4].

The most significant negative impact during the construction of infrastructure is caused by deforestation and land preparation works, as these operations put pressure on all environmental factors.

During land preparation and deforestation works, by manipulating the fuels used for the equipment and transportation means, there are generated a series of air pollutants: NO_X, SO_2, CO, VOC_S, suspended and sedimentable particles, which affect air quality by reducing its filtering capacity. Through dispersion and sedimentation, solid air pollutants particles are deposited on the soil surface and this may lead to structural changes in the soil profile. Also, changes in soil profile may occur as a result of oil and fuel leakages associated with technical failure of the equipment used for deforestation works or as a result of final removal of trees from deforested areas. Moreover, on the deforested surfaces there is also a decrease in soil fertility, because of the lack of dead organic matter coming from arboretum [3].

By clearing the vegetation and deforestation, the biotic compounds are removed and the soil ecosystem is completely destroyed [4]. After the surface is prepared for construction, the next phase is the construction of road superstructure. First, a foundation layer made of ballast is laid and compacted; then, it is laid a layer comprised of crushed stone, followed by a layer of asphalt mixture and a layer made of sieve binder. The upper surface, which is also called wear layer, is the last layer and it is comprised of asphalt concrete.

Asphalt products are construction materials resulted from specific technological processes and they are comprised of different aggregates, bitumen and other additives. These products must fulfill the following legal requirements:

- The aggregates used for bituminous coatings can be made of processed or unprocessed natural rocks; the minimum class to which they belong and also the physical-mechanical characteristics of their origin rock must be in accordance with SR 667.
- The filler used for making bituminous road coatings must be in accordance with SR EN 13043 and/or STAS 539;
- The binders must be in accordance with SR EN 12591;
- The additives may be added directly into the bitumen or in the asphalt mixture and they must fulfill SR EN 13108 requirements.

All these compounds are heated and then they are mixed up in concrete and asphalt mixtures stations. The installations used in the technological process of obtaining concrete and asphalt mixtures are sources of pollutant emissions, such as: particulate matter, VOC_S, SO_2, CO, NO_X [6].

Asphalt is a source of VOCs emissions, in all phases, from its production to road construction and also in the road exploitation phase. A study conducted by Peeyush Khare and co. in 2020 [7], during asphalting works, has shown that the total quantity of emissions doubled when the temperature rose from 40ºC to 60ºC and it increased with 70% (average value) when the temperature raised with 20ºC from 60ºC to 140ºC.

The presence of suspended particulate matter in air may trigger changes in cardiac physiology and/or a lot of biochemical changes in the blood (thrombosis caused by increased blood viscosity) and because of that the proper functioning of cardiovascular system is at risk. Old persons, with preexistent cardiac diseases are more susceptible to suffer from changings in cardiac rate related to PM pollution. It is known that PM_{10} are responsible for an increase in mortality and/or morbidity. Also, PM exposure may lead to pulmonary inflammation and sudden death, but it can also affect digestive system [2].

Nitrogen oxides NOx and sulfur dioxide result from the combustion process, when the combustion of fuels takes place at high temperatures. Usually, they are generated by road traffic and industrial activities. These oxides are responsible for acid rain, photochemical smog and greenhouse effect. Nitrogen oxides have a significant contribution also in water and soil acidification, by their accumulation in the soil following the excessive use of nitrogen as a fertilizer [5]. Suspended particulate matter PM ($PM_{2,5}$ and PM_{10}) come both from natural and anthropic sources and they represent a complex mixture of very small particles and liquid drops (aerosols), covering a wide range of chemical compositions and diameters and having a negative impact on the environment, as they act as a greenhouse gas [2].

2. Materials and methods

In this study, there were estimated the quantities of air emissions generated during the construction of a street in Alba Iulia city and also during the production of the asphalt products needed for the construction works. The emissions of air pollutants were estimated in accordance with Order 3299 of 28.08.2021 for the approval of the methodology for conducting and reporting inventories on emissions of pollutants into the atmosphere [8].

2.1. Description of Project

For this study, it was chosen Brându ei Street, which is located in Alba Iulia city, Alba county, from the intersection with Lalelelor Street to the intersection with Carpenului Street, on a 2532 m length. Due to the fact that the street belongs to the category of importance "C", class of importance III, for construction works there were used the following asphalt mixtures, in accordance with SR EN 13108-1:

a) 30 cm ballast foundation layer: made of a mixture of natural aggregates originated from stable rocks, that do not alter in the presence of water, air or/and frost, free of foreign substances and having a maximum granulation of 63 mm. The ballast was brought by trucks from the sorting site directly at the construction site, without being stored in a construction site organization. The spreading and leveling of the ballast were done with the help of a bulldozer and for the compacting works it was used a compactor cylinder. The execution works for the foundation layer were conducted in accordance with STAS 6400-84 and SR EN 13242.

b) 7 cm bonding layer (binder), made of BAD 20 asphalt mixture: it is an intermediate layer, which connects the foundation layer and the wear layer. The BAD 20 asphalt mixture was comprised of the following materials: bitumen, natural aggregates 16/20, sand 0/4 (50%) mixed with natural sand 0/4 (50%), limestone filler.

c) 6 cm wear layer, made of BA 16 asphalt mixture: this is the final layer, the road tread layer, and it is laid over the bonding layer. The BA 16 asphalt mixture is comprised of: bitumen, natural aggregates – 8/16, crushing sand – 0/4 (75%) mixed with natural sand 0/4 (25%), limestone filler.

2.2. Asphalt mixtures

For the construction works, there were used hot asphalt mixtures with fast drying (RC – rapid cure), containing 8% bitumen; the bitumen contains 35% solvent (naphtha – volatile substance obtained from petroleum) and it is applied in accordance with SR 754.

Table 1 - Classification of naphtha, according to the Regulation (EC) No. 1272/2008

Name of substance or mixture	*Classification and labelling of chemical substances (according to REGULATION (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures)*		
	Category hazardous /non-hazardous (H/N)	*Hazard class and category code(s)*	*Hazard phrase*
Kem- Kromic	H	Flam. Liq. 3 STOT SE 3 STOT RE 1 Asp. Tox. 1 Aquatic Chronic 3	H 226 H 336 H 372 H 304 H 412

2.3. Asphalt mixture production plant

The asphalt mixtures needed for construction works were prepared from new aggregates, in a fix hot preparation installation with countercurrent drying-kneading drum, which had a production capacity of 120 tons /hour and which was equipped with installations for retention of mineral particles and flue gas filtration. The station has a 12h /24h operating schedule.

Hot mix asphalt mixture is produced in an installation which has the following main compounds:

- consumer warehouse for aggregates, filler, bitumen, equipped with silos for

new aggregates and tanks for bitumen storage
- supply and pre-dosing system for aggregates
- vibrating equipment
- dosing system for aggregates, filler, bitumen
- aggregates heating and mixing installation
- bitumen heating system
- retaining system for the fine particles coming from aggregate dedusting; this system has a 99% efficiency and it ensures the collection of fine particles, so that they can be reused
- transportation system for hot materials;
- mixture storage system.

2.4. The calculation of the quantity of asphalt mixture needed for the construction works

In order to calculate the quantity of asphalt mixtures, there were taken into account the following parameters: road length 2532 meters, road width 6 meters, bonding layer height-7 cm, wear layer height 6 cm, the specific weight of asphalt mixtures 2,35 tons/cubic meter. Thus, the quantity needed for the construction works, resulted from calculations, was ca. 4641,156 tons. As the production capacity of the installation is 120 tons/hour, it resulted that, for the production of this quantity of mixtures, the station has to work ca. 39 hours.

2.5. The calculation of the dust emissions generated by aggregates storage

The emissions coming from raw materials storage are fugitive emissions. Therefore, the estimation of this type of emissions will be done using the guide: EMEP/EPA Storage, handling and transport of mineral products, 2013, cod NFR 2.A.5.c. According to this guide, the emissions coming from controlled aggregates storages is presented in Table 2. Taking into account the fact that the aggregates warehouse covers a surface of 0,155 ha and considering that the time needed to prepare the quantity of mixtures necessary for the construction works is ca. 4 days, it was possible to estimate the quantity of pollutants emitted during the Brandusei Street construction (Table 3).

Table 2 - Emission factors for mineral products storage in controlled storages

Pollutant	*Emission factors ton/ha/year*	*95 % Confidence interval*	
		lower	*upper*
TSP	1,64	0,62	3,28
PM_{10}	0,82	0,41	1,64
$PM_{2,5}$	0,082	0,041	0,164

2.6. Emissions generated during the production of asphalt

The emissions of pollutants were estimated using the method regulated by the Order no. 3299 from 28/08/12, Annex 1 „Procedure for the compillation of local

Table 3 – Estimated dust emissions during aggregates storage

Pollutant	*Mass flow*				
	tons/4 days	*g/4 days*	*tons/day*	*g/day*	*(g/s)*
TSP	0,0028	2800	0,0007	700	0,008
PM_{10}	0,0014	1400	0,00035	350	0,004
$PM_{2,5}$	0,00014	140	0,000035	35	0,0004

emsissions inventories and national emissions inventory, in accordance with the requirements of the EMEP/EEA Guide".

The main sources of air pollution associated with the functioning of the station for the preparation of 4641,156 tons of asphalt mixture are:

- the combustion installations of the asphalt mixture station;
- the equipment used for the manipulation of raw materials inside the station;
- the means of transportation used for raw materials and final products.

The main pollutants emitted during the functioning of the installation are:

- the gases emitted as a result of fuel combustion, necessary in order to obtain high temperatures for aggregates drying and bitumen heating operations (CO and CO_2, NO_X, hydrocarbons, VOC_S);
- sedimentable and suspended mineral particles, coming from the manipulation, storage and processing of mineral aggregates
- exhaust gases, emitted by the technical equipment that manipulates raw materials inside the station (NO_X, CO_X, VOC_S, particulate matter).

The methodology applied for the estimation of emissions generated during the preparation of asphalt mixtures is US EPA/AP – 42, chapter 11.1 „Hot mix asphalt plants", with first level approach. This is based on emission factors, which are used on the assumption that all industrial units with the same production lines have the same emissions structure. Emission factors are usually established by conducting measurements at one or more installations from the same activity field, but there can also be predetermined emission factors, whose values are taken form specialty literature. Emission estimation based on emission factors requires data concerning the type of activity considered, expressed in fuel consumption and production.

The general formula used to estimate the emission of a certain pollutant coming from an activity or installation is:

$$E_{pollutant} = AR_{production} @ EF_{pollutant}$$

where:

$E_{pollutant}$=the emission of a specified pollutant;

$AR_{production}$=activity rate for the paving of the road with asphalt mixtures;

$EF_{pollutant}$=emission factor for the specified pollutant [g/t].

2.6.1. Emissions of particulate and $NMVOC_S$

During the functioning of the installation were calculated using the emission factors for drum mix hot mix asphalt plants, with no emission control systems, in accordance with EEA Guide 2016, NFR 2.D.3.b., SNAP 040611, presented in table 4.

Because the asphaltic mixture station is provided with particle bag filters, having an efficiency of 99%, the emission factors presented above had to be reduced considering the filters efficiency.

Table 4. Particulate matter emission factors for drum mix hot mix asphalt plants (in accordance with EEA Guide 2016)

Pollutant	*Emission factors (g/asphalt tons)*	*95 % Confidence interval*	
		lower	*upper*
NMVOCs	15	3	100
TSP	13.000	10	140000
PM_{10}	3.000	20	10000
$PM_{2,5}$	700	1	2000

Considering a functioning schedule of 12 hours/day and an asphalt preparation capacity of 120 tons/hour, the quantities of emissions (g/s) are:

Table 5 - Estimated dust and NMVOCs emissions during the preparation of the mixture

Pollutant	*Emission factor (g/asphalt tons)*	*Emissions (Kg/ 4641,156 asphalt tons)*	*Mass flow (g/s)*
NMVOCs	15	69,617	0,5
TSP	130	603,35	4,33
PM_{10}	30	139,23	1
$PM_{2,5}$	7	32,48	0,23

2.6.2. Emission of gases from the exhaust chimney

They are stationary, ducted sources of pollution, the main exhausted gases being: CO, NO_X, SO_X. The emissions were estimated considering the emission factors for combustion operations in production and construction activities, NFR 1.A.2, SNAP 03, for asphalt stations, from EEA Guide 2013. In accordance with this document, the emission factors are:

Table 6 - Emission factors for combustion gases (in accordance with EEA Guide 2013)

Pollutant	*Emission factors (g/asphalt tons)*	*95 % Confidence interval*	
		lower	*lower*
CO	200	100	300
NO_x	35,6	12,5	60
SO_x	17,7	2,3	44

The emission of gases during the production of the quantity of asphalt mixtures needed for the road pavement are presented in the following table:

Table 7 – Estimated gases emissions during mixture preparation

Pollutant	*Emissions*	
	Kg/4641,156 t	*g/4641,156 t*
CO	928,231	928.231
NO_x	165,225	165.225
SO_x	82,148	82.148

2.6.3. The calculation of emissions generated by exhaust gases associated with intern traffic

In order to calculate these emissions, there were taken into account the machineries used inside the asphalt station (3 dumpers, 1 front loader and 2 bucket elevators), with a total fuel consumption of ca. 2000 l (ca. 1700 kg) for the entire operating period needed to produce the quantity of asphalt required to pave the analyzed road.

During the operating of Diesel engine equipment, there are generated a series of pollutants, such as: NO_X, CO, $NMVOC_S$, NH_3, N_2O, PM. These emissions are exhausted directly into the atmosphere, during the following operations: the filling of silo with aggregates, the transportation of materials and final products inside the station. All these sources are mobile and fugitive, with a temporary, strictly local and low level impact.

The emissions were estimated taking into account the following emission factors for exhaust gases from transportation field – for heavy-duty Diesel vehicles – in accordance with EMEP/EEA Guide 2013, NFR code 1.A.3.b.iii.

Table 8 - Average emission factors for exhaust gases coming from heavy-duty Diesel Vehicle

Pollutant	*Emission factors (g/Kg fuel)*	*95 % Confidence interval*	
		lower	*lower*
CO	7,58	5,73	10,57
NMVOCs	1,92	1,33	3,77
NH_3	0,013	0,010	0,018
NO_x	33,37	28,34	38,29
N_2O	0,051	0,030	0,089
PM	0,94	0,61	1,57

By using the emission factors mentioned above and the required quantity of fuel, there were calculated total emissions generated during this activity; the mass flow for each pollutant is presented in the table below:

Table 9 - Estimated exhaust gases emissions coming from technical equipment

Pollutant	*Total emissions (g/1700 kg fuel)*	*Mass flow (at a functioning program of 39 h)*	
		g/h	*g/s*
CO	12886	330,4	0,091
NMVOCs	3264	83,69	0,023
NH_3	22,1	0,56	0,0001
NO_x	56729	1454,58	0,404
N_2O	86,7	2,22	0,0006
PM	1598	40,97	0,011

2.7. Emissions generated during the asphalt paving works and thereafter

The main pollutants generated during the paving works are NMVOCs, resulted from the evaporation of the solvent (naphtha). Other air pollution source in this phase is represented by exhaust gases coming from the equipment used to transport asphalt from the production plant to the construction site and those coming from the machineries used to lay, level and compact asphalt layers.

2.7.1. VOC_S emissions from liquid asphalt cement

The estimation of emissions associated with paving works is based on the same methodology, US EPA/AP-42, chapter 4.5 "Asphalt Paving Operations", third level approach, in accordance with EMEP/EEA Guide. The parameters required for the estimation are: the type and the quantity of asphalt and the quantity of solvent from the asphalt. According to this methodology, for a solvent quantity of 35%, it is considered that 95% of it evaporates on long term, the remaining 5% being permanently stored on the road surface, after paving. The evaporation of the solvent takes place as it follows:

- 75% in the first day after paving;
- 90% in the first month after paving;
- 95% in the first 4 months after paving;

Knowing the fact that hot asphalt mixtures contain 8% bitumen, the quantity of solvent resulted to be 130 tons; VOCs emissions during and after the asphalt paving are presented in the table below:

Table 10 - Estimated NMVOCs emissions during and after the asphalt paving works

Pollutant	*Total quantity of evaporated solvent (t/4641,156 mixture tons)*	*Quantity of evaporated solvent (tons)*			
		First day	*First month*	*First 4 months*	*On long term*
NMVOCs	123,5	92,625	111,15	117,32	123,5

2.7.2 Exhaust gases emissions generated by the equipment used for asphalt paving works

The parameters considered for the estimation of the emissions generated in the paving phase are:

- time required to finish the works: 32 hours;
- specific fuel consumption of the equipment used during paving works (4 dump trucks, 2 distributors - asphalt paver, 3 compactor cylinders and 1 brush machine): 2900 lt Diesel fuel (ca. 2465 kg).

The emissions were estimated considering the following average emission factors for exhaust gases generated by transportation – for heavy-duty diesel vehicles – in accordance with EMEP/EEA Guide 2013, code NFR 1.A.3.b.iii. The results are presented in the table below.

Table 11 - Estimated exhaust gases emissions generated by equipment during asphalt paving

Pollutant	*Emission factor (g/ 2465 kg fuel)*	*Estimated emissions (g/ 2465 kg fuel)*	*Mass flow (at a functioning program of 39 h)*	
			g/h	*g/s*
CO	7,58	18.684,7	583	0,162
NMVOCs	1,92	4.732,8	147,9	0,041
NH_3	0,013	32,04	1,001	0,0002
NO_X	33,37	82.257	2570,5	0,71
N_2O	0,051	15,15	0,47	0,0001
PM	0,94	2.317,1	72,4	0,02

3. Conclusions

This study showed that infrastructure development represents a significant source of air pollution, in all working phases and even after the construction works are finished. Estimated impact is temporary and reversible and it manifests itself mostly during construction works. The equipment operated in the asphalt production phase and in the construction phase contributes to changes in air quality on a limited area, at the construction site, because of the generated emissions (exhaust gases, NMVOCs and TSP). Also, raw materials silos represent a source of particle emission, with a reduced impact on the quality of air and vegetation in the area.

Although most of these emissions are fugitive, they can be estimated by using different guides and methods described in various legislative documents. Emission estimation is important for environmental impact assessment. Even though a significant part of these emissions reach the atmosphere, the quantity of air polluting emissions can be reduced by using high-performance equipment for asphalt production and transportation or by adopting preventive measures in order to reduce the quantities of TSP released into the atmosphere. However, the environmental impact assessment studies must consider also the positive environmental impact of infrastructure development, after road construction works are finished, especially on what socio-economic aspects are concerned.

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