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Analysis of vehicular pollution in the road tunnel of Kherrata (Algeria)

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Abstract

The aim of the study is to analyse the amount of atmospheric pollution emitted by vehicular traffic in the road tunnel of Kherrata which is situated between the towns of Bejaia (36°45'N,05°06'E) and Setif (36°11'N,05°15'E) in Algeria. The geometric characteristics of the tunnel are: the length (5865.25 m), the height (6.5 m) and the mean slope (5.1 %).

Captors of particulate pollution were installed, they permit the measurement of the suspended particles concentrations at any time. Moreover, we installed a wash system operating by remote control in order to count the number of vehicles crossing the tunnel during the same period.

The vehicles crossing the tunnel were classified according to the following characteristics: type (bus, lorry, car), fuel (diesel, essence) and direction (descendant, climbing).

In order to find possible relationships between atmospheric pollutants and the sources (road traffic), taking into account the type, the fuel and the direction, we applied the statistic methods of correlation-regression and principal component analysis.

To estimate the amount of pollution at the emission (exhaust pipe), we use a mathematical model of pollution dispersion: the box model.

We find that the number of vehicles is related significantly and linearly to increase of atmospheric pollutants in the tunnel, the vehicles using diesel as fuel emit more pollutants. Taking into account the slope parameter, we remark that the descendant vehicles emit less pollutants than the others. With the help of box model, we find a significant correlation (R=0.827) between the pollutants measured and the pollutants estimated in emission (exhaust pipe).

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1 Introduction

Atmospheric pollution has a harmful impact on health [1][2] and vegetation [3][4]. Traffic is undoubtedly one of the important source of this pollution [5][6]. In urban areas, automobile exhaust emissions are more important in intersections of roadways, traffic jam and narrow streets [7][8]. Moreover, studies have shown very high concentrations of pollutants in poorly ventilated, confined spaces used by motor vehicles. These include parking garages, tunnels and inderpasses [9].

Road tunnels are part of a solution to traffic management, but, in order to provide healthy and safe conditions for the users, it is necessary to ventilate the tunnels [10][11][12]. Sometimes, the ventilation in tunnels is insufficient because of the meteorological and topographical factors (slight wind, valley,...), it is so important to control the pollution in the tunnel in order to alert when pollution reaches high levels. Indeed, exposure to air pollution in road tunnel can create disastrous effects on health [13]. Several tunnel studies have been conducted to compare predicted and observed emissions. Most efforts thus far have compared the observed ratio of pollutant concentrations with the predicted ratio of pollutant emissions based upon outputs from predictive models [14][15].

The main aim of this study is to analyse the amount of atmospheric pollution emitted by vehicular traffic in the road tunnel of Kherrata. To develop this work, we propose firstly a theoretical model of pollution diffusion into the tunnel. Then, we analyse the amount of pollution using captors installed in five places of the tunnel. In order to find possible relationships between amounts of particulate pollution and traffic, we use the statistical methods such as correlation, linear regression and principal components analysis (or factor analysis).

2 Experimental and methods

The tunnel considered has a length equal to 5700 m. Two series of 41 ventilators were installed along the tunnel. When the level 1 of pollution is reached, the first series of ventilators started. When pollution raised to the level 2, the second series was activated. When the level 3 of pollution is reached, an alarm signal is actuated and the access to the tunnel is closed.

The traffic density and type of vehicles were determined by a video system operating with remote control. The sample time is taken equal to 5 mn.

The suspended particles emitted by exhaust pipes were measured using opacimeters. A part of exhaust gas was introduced in a measure chamber with a probe. The chamber is provided with a light source, a captor and a photocell. After its passage across the sample, the light intensity decreased according to the Beer-Lambert formula: $I = I_0 \exp(-kx)$, I and I_0 are respectively the transmitted and

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incident intensities, k is the extinct coefficient, and x is the thickness of the cell sample. The parameter C representing the opacity by suspended particles is calculated according to the following formula: $C = \frac{I_0 - I}{I_0} 100$. C is expressed in %.

To estimate the amount of pollution at the emission (exhaust pipe), we use a mathematical model of pollution dispersion: the box model. This model is based on the knowledge of the emission factors, according to the type, the age and the fuel used by the vehicles. The pollutants which are estimated are CO, NO, C_xH_y and aerosols. We suppose that the volume of mixing layer is constant.

The relationships between opacity, traffic and amount of pollutants at the emission were examined using principal components analysis (PCA) that employs methods described by Saucy et al.[16] and Anderson et al.[17]. A VARIMAX rotation was used in the factor analysis calculation. Previous works had reported a similar methodology to analyse this kind of data [18][19].

3 Modelling pollution into the tunnel

3.1 Assumptions and equations

It is necessary to model the evolution of pollution into the tunnel taking into account the vehicular emission, the ventilation and the turbulence. The model used to describe the pollution diffusion into the tunnel is represented by the following equation:

$$\frac{\partial C}{\partial t} + \frac{\partial}{\partial x}(CU) = \frac{\partial T_{atm}}{\partial x} + \frac{\partial T_{veh}}{\partial x} + S - P$$

Where:

- C represents the pollution concentration,
- U: the wind speed into the tunnel,
- S: the emission rate of source pollution,
- P: the amount of fresh air introduced into the tunnel with ventilation or the amount of polluted air expelled from the tunnel,
- T_{atm}: external turbulence parameter = $K\frac{\partial C}{\partial x}$,
- T_{veh} : turbulence caused by automobiles into the tunnel,
- K: diffusion coefficient.

We assume that the pollution is well mixed into the tunnel and we take into account only the variations of pollution concentration at the extremities of the tunnel. After these simplifications, we obtain the following equation:

$$\frac{\partial C}{\partial t} = -\frac{1}{L}\left[\left[C(U + nU_{veh}) - K\frac{\partial C}{\partial x}\right]_{left} - \left[C(U + nU_{veh}) - K\frac{\partial C}{\partial x}\right]_{right}\right] + S - P$$

$$\Rightarrow \frac{\partial C}{\partial t} = \frac{1}{L}(C_1 - C)\left(U + nU_{veh} + \frac{2K}{L} + \frac{R}{A}\right) + S$$

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U, Uveh, and L represent respectively the wind speed, the mean vehicular speed and the tunnel length. The parameter n is related to the sections of the tunnel and the vehicles.

P= R(C-$C_{external}$) and R represents the exchange air rate between tunnel and external environment, assuming that pollutants concentration at the extremities of the tunnel are equal:

$C_{south} = C_{north} = C_{ext} = C_1$

The equation becomes then as follows:

$$\frac{\partial C}{\partial t} = \frac{1}{L}(C_1 - C)\left(U + nU_{veh} + \frac{2K}{L} + \frac{R}{A}\right) + S$$

The solution is: $C(t) = C_\infty\left(1 - \exp(-\frac{t}{\tau}\right)$, where

$$C_\infty = C_1 + \frac{SL}{U + nU_{veh} + \frac{2K}{L} + \frac{R}{A}}$$

and

$$\tau = \frac{L}{U + nU_{veh} + \frac{2K}{L} + \frac{R}{A}}$$

3.2 Experimental confirmation of the model

In order to test the theoretical model of pollution evolution into the tunnel, we measured the opacity and counted simultaneously the number of vehicles across the tunnel in the two senses. The measure campaign was led in the period 02-12 July 2000. The opacity recorded at the instant t must correspond to the pollution emitted by vehicles entering into the tunnel in the period t-Δt to t and vehicles leaving the tunnel in the period t to t+Δt. Δt is equal appreciatively to 5 mn. In the figure 1, we show the opacity measured during 24 h. We remark the peaks of opacity at instants of intense traffic and minimum tending to zero in night (plateau). In the figure 2, we compare the evolutions of opacity measured and opacity estimated by the theoretical model. The emission rate of source pollution S is related to the vehicular number N_{veh} using the following formula: $S = E_b N_{veh} P_{veh}$, P_{veh} and E_b represent respectively the weight of vehicles and the basis emission of diesel vehicles. We remark that the evolutions are similar; the theoretical model used is so efficient.

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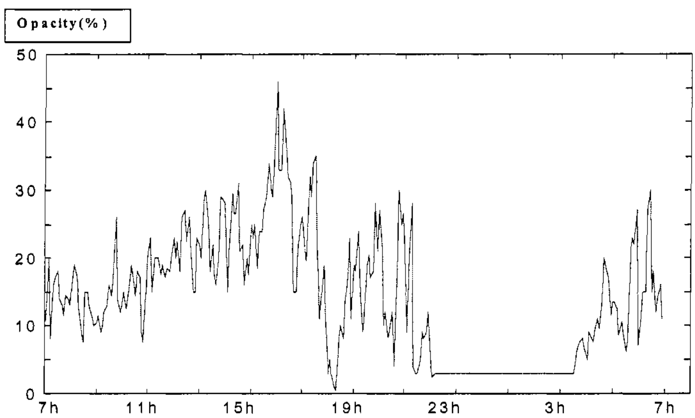

Figure 1: Evolution of opacity from July 2nd, at 07 H, to July 3rd at 07 H.

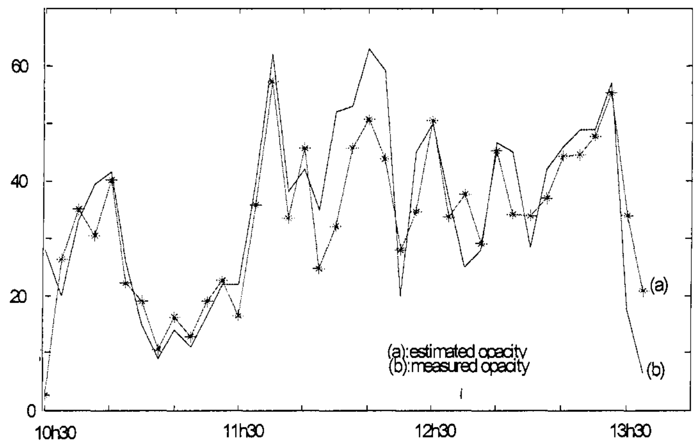

Figure 2: Comparison of opacities evolutions during three hours in July 2nd 2000

4 Estimation of pollution emission

To estimate the amount of pollution emitted by exhaust pipes, we use the box model. This model is adapted to the problem of pollution estimation in the tunnel. Assuming that the pollution in the tunnel is distributed uniformly, we can suppose that the dimensions of the box is identical to those of the tunnel. We use the model described by Degobert [20]: $C = \frac{qN}{LS}$

Where:

- L: the length necessary to obtain an uniform distribution of the pollution, it is also the length of the tunnel;
- N: number of vehicles across the tunnel during 5 minutes;

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- S: transverse surface of the tunnel;
- q: emission factor according to fuel used, vehicular type and emitted pollutant.

The values of emission factors are those suggested by Weaver [21] and shown in the table 1.

Table 1: Emission factors (gram/km)

	CO	NO	Hydrocarbons	Suspended particles
Light cars essence	31	1,5	2,9	1 ,1
Light cars diesel	1 ,30	0,9	0,1	0,3
Heavy vehicles diesel	18,8	16,2	5,78	1,6

From these data, we calculate the amount of pollution emitted by exhaust pipes. In the figure 3, we show the regression curve between opacity measured in % (PAR_MEAS) and the concentration of suspended particles (PAR_EST) calculated using the box model. We remark that the relationship is very significant (R= 0.827).

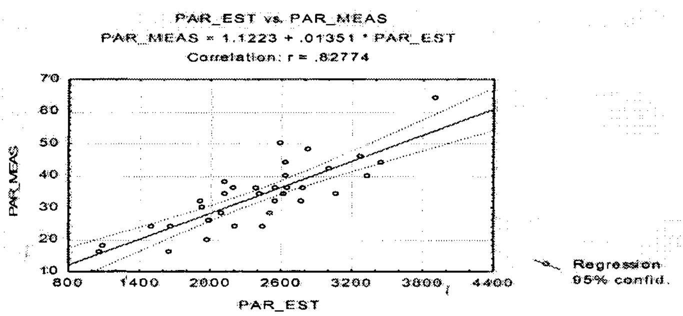

Figure 3: Regression curve between measured opacity (PAR_MEAS), expressed in %, and the concentration of suspended particles emitted by exhaust pipes (in $\mu g/m^3$)

5 Influence of vehicle number and slope on the pollution

The vehicle number is classified according to the fuel used (essence, diesel), the vehicle type (light, heavy cars) and the direction (descending or climbing). The pollution measured is represented by the opacities measured in the middle of the tunnel. In order to study statistically the relationships between pollution measured and vehicle number across the tunnel, we use thirteen variables: CLV (number of climbing light vehicles), DLV (number of descending light vehicles), CMV (mean number of climbing vehicles), DMV (mean number of descending vehicles), DHV (number of descending heavy vehicles used diesel), CTV (total

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number of climbing vehicles), DTV (total number of descending vehicles), CVD (number of climbing vehicles used diesel), TV (number of total vehicles), CHV (number of climbing heavy vehicles), DVD (number of descending vehicles used diesel), OP_N (opacity measured in the north of the middle tunnel), and OP_S (opacity measured in the south of the middle tunnel).

The result for the correlation matrix of precedent variables is shown in table 2. The correlation matrix shows that the opacity at the north of the middle tunnel (OP_N) is associated significantly with the number of climbing vehicles using diesel (CVD), the total number of climbing vehicles (CTV) and total number of vehicles across the tunnel (TV). The correlation coefficient are respectively equal to 0.68 , 0.67 and 0.80.

The factor analysis was carried out by the principal component analysis (PCA), beginning this by means of calculating magnitude and percentage of variance of eigenvalues attributed to each factor. It was considered to take into account the first two factors considering a percent of variance equal to 91.87 %. Then, a VARIMAX normalized rotation was carried out, the calculation of the factor loading increases the separation between the elements in the graph. The coordinates corresponding to the variables in the two factorial axes were obtained (table 3) and their representation after rotation is shown in figure 4. The results displayed in the table and the figure show four groups representing a clear statistical association between elements:

group 1: opacity at the north of the middle tunnel (OP_N), number of climbing vehicles (CLV and CHV),

group 2: it is constituted of CMV, CVD and CTV (number of climbing vehicles);

group 3: opacity at the south of the middle tunnel (OP_S) and total number of vehicles (TV);

group 4: number of descending vehicles.

Table 2: Correlation matrix
Casewise deletion of MD
N=35

	CMV	CHV	CVD	CLV	CTV	DLV	DMV	DVD	DHV	DTV	TV	OP_N	OP_S
CMV	1.	.33	.87	.35	.80	.06	.13	-.01	-.22	.04	.70	.53	.45
CHV	.33	1.	.74	.20	.63	-.05	.17	.09	-.07	.00	.54	.59	.43
CVD	.87	.74	1.	.36	.88	.02	.18	.04	-.19	.0	.70	.68	.54
CLV	.35	.20	.36	1.	.75	-.03	-.12	-.12	-.08	-.07	.60	.38	.14
CTV	.80	.63	.88	.75	1.	-.00	.07	-.03	-.17	-.02	.84	.67	.45
DLV	.06	-.05	.02	-.03	-.00	1.	.55	.56	.38	.93	.50	.27	-.03
DMV	.13	.17	.18	-.12	.07	.55	1.	.90	.44	.77	.48	.54	.06
DVD	-.01	.09	.04	-.12	-.03	.56	.90	1.	.79	.82	.42	.54	.01
DHV	-.22	-.07	-.19	-.08	-.17	.38	.44	.79	1.	.60	.18	.34	-.06
DTV	.04	.00	.03	-.07	-.02	.93	.77	.82	.60	1.	.53	.42	-.02
TV	.70	.54	.77	.60	.84	.50	.48	.42	.18	.53	1.	.80	.37
OP_N	.53	.59	.68	.38	.67	.27	.54	.54	.34	.42	.80	1.	.52
OP_S	.45	.43	.54	.14	.45	-.03	.06	.01	-.06	-.02	.37	.52	1.

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Table 3: Factor Loadings (Varimax normalized)
Extraction: Principal components
(Marked loadings are > .700000)

	Factor 1	Factor 2
CMV	.812434	-.019559
CHV	.692338	.032149
CVD	.929696	.002724
CLV	.590437	-.114159
CTV	.952056	-.055012
DLV	.027881	.772672
DMV	.149890	.839900
DVD	.022541	.932494
DHV	-.163960	.731444
DTV	.029002	.939657
TV	.824168	.462137
OP_N	.739702	.485664
OP_S	.588404	-.020641
Expl.Var	4.882849	4.057313
Prp.Totl	.375604	.312101

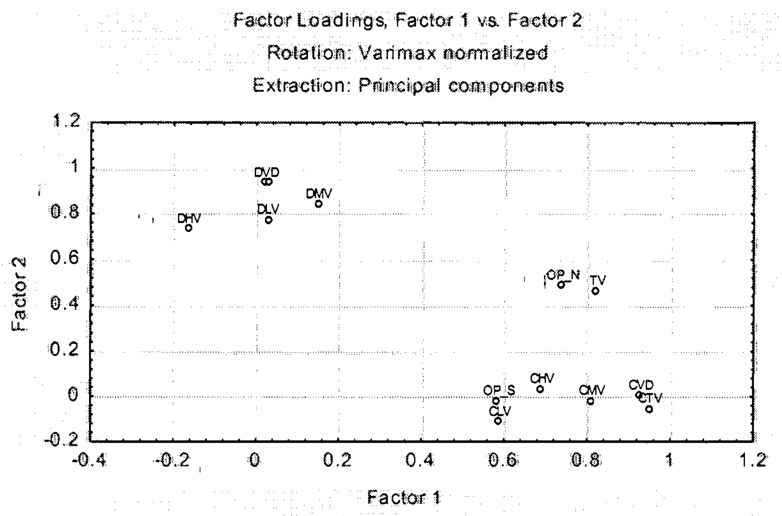

Figure 4: Component analysis of vehicle number, according to type, fuel used and direction, and opacity

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Conclusion

This study confirms the important part of vehicles in the pollution of the tunnel. We find that the number of vehicles is related significantly and linearly to increase of atmospheric pollutants in the tunnel, the vehicles using diesel as fuel emit more pollutants. Taking into account the slope parameter, we remark that the climbing vehicles emit more pollutants than the descendant vehicles. With the help of box model, we find a significant correlation (R=0.82) between the pollutants measured and the pollutants estimated in emission (exhaust pipe). Furthermore, we can cite the seasonal factor as an other phenomenon which has an impact on the accumulation of the pollution in the tunnel. In summer, the wind is calm and the traffic is important, this results that the ventilators cannot follow the rhythm and the pollution in the tunnel exceeds the tolerable threshold.

References

[1] Ferris, B.G. Health effects of exposure to low levels of regulated air pollutants. A critical review. J. Air Pollut. Control Assoc., 28, pp. 482-497, 1978.
[2] Richards, W., Azen, S.P., Weiss, J., Stocking, S., Churcj, J. Los Angeles air pollution and asthma in children. Ann. Allerrgy, 47, pp. 348-354, 1981.
[3] Bolsinger, M., and Walter, F. Effect of air pollution at a motorway on the infestation of viburnum opulus by aphis fabae. European J. of Forest Pathology, 14, 4 -5, pp. 256-260, 1984.
[4] Alfani, A., Maisto, G., Iovieno, P., Rutigliano, F., Bartoli, G. Leaf contamination by atmospheric pollutants as assessed by elemental analysis of leaf tissue, leaf surface deposit and soil. J. of Plant Physiol., 48, pp. 243-248, 1996.
[5] Granier, L., and Chevreuil, M. Automobile traffic: a source of PCBs to the atmosphere. Chemosphere, 23, 6, pp. 785-788, 1991.
[6] Campos, I.C.B., Pimental, A.S., Corrêa, S.M., Arbilla, G. Simulation of air pollution from mobile source emissions in the city of Rio de Janeiro. J. Braz. Chem. Soc., 10, 3, pp. 203-208, 1999.
[7] Rao, S.T., Sistla, G., Eskeridge, R.E., Peterson, W.B. Turbulent diffusion behind vehicles: evaluation of roadway model. Atm. Environ., 20, pp. 1095-1103, 1986.
[8] Sini, J.F., Anquetin, S., Mestayer, P.G. Pollutant dispersion and thermal effects in urban street canyons. Atm. Environ., 30, pp. 2659-2677, 1996.
[9] Schwela, D., and Zali, O. Urban traffic pollution, E & FN Spon, New York, 1999.
[10] Jacques, E.J., Possoz, L. Road tunnels and the environment. Proceedings of a workshop on "measurement techniques in energy systems and processes", pp. 83-108, 1996.
[11] Haerter, A. Road tunnel air and the environment. Aerodynamics and ventilation of vehicle tunnels. Elsevier Science Publishers Ltd, England, pp. 3-20, 1991.

Paper from: *Air Pollution X*, CA Brebbia & JF Martin-Duque (Editors).
ISBN 1-85312-916-X

[12] Bellasio, R. Modelling traffic air pollution in road tunnel. Atm. Environ., 31, pp. 1539-1551, 1997.
[13] Svartengen, M., Strand, V., Bylin, G., Järup, L., Pershagen, G. Short-term exposure to air pollution in a road tunnel enhances the asthmatic response to allergen, Eur. Respir. J., 15, pp. 716-724, 2000.
[14] Ingals, M.N. On-road vehicle emission factors from measurements in a Los Angeles area tunnel, N° 89-137.3, Air & Waste Management 82nd Annual Meeting, Anahiem, CA, 1989.
[15] Pierson, W.R., Gertler, A.W., Bradow, R. Comparison of the SCAQS tunnel study with other on-road vehicle emission data, J. Air and Waste Manag. Ass., 40 (11), 1990.
[16] Saucy, D.A., J.R. Anderson and P.R. Buseck, Aerosol particle characteristics determined by combined cluster and principal component analysis, *J. Geophys. Res*, 96, 7407-7414, 1991.
[17] Anderson, J.R., P.R. Buseck and T.L. Patterson, Characterization of the Bermuda tropospheric aerosol by combined individual-particle and bulk-aerosol analysis, *Atm. Environ.*, 30(2), 319-338, 1996.
[18] Rojas, C.M, P. Artaxo and R. Grieken, Aerosols in Santiago de Chile: a study using modeling with X-ray fluorescence and single particle analysis, *Atm. Environ.*, 24B(2), 227-241, 1990.
[19] Karue, J., A.M. Kingua, and A.H.S. El-Busaidy, Measured components in total suspended particulate matter in Kenyan urban area, *Atm. Environ.*, 26B(4), 505-511, 1992
[20] Degobert, P. Autimobile et pollution, Ed. Technip Paris, 544 p, 1992.
[21] Weaver, P., Walsh, C. Air pollution from motors vehicles, Ed. World Bank, Washington DC, 250 p, 1973.