Global J. Environ. Sci. Manage.,4(3): *-*, Summer 2018
DOI: 10.22034/gjesm.2018.04.03.00*

CASE STUDY

Modeling of carbon monoxide dispersion around the urban tunnel portals

M. Rafiei[1,2,*], P.J. Sturm[2]

[1]*Department of Mechanical Engineering, Semnan Branch, Islamic Azad University, Semnan, Iran*

[2]*Institute of Internal Combustion Engines and Thermodynamics – IVT, Graz University of Technology, Austria*

Received 13 January 2018; revised 7 May 2018; accepted 1 June 2018; available online 1 July 2018

ABSTRACT: The aim of this study is to investigate the problems caused by discharge of polluted air from tunnels into the environment with a specific focus on residential areas. In city tunnels, portal or stacks, pollutant management is a big challenge. Nowadays, air quality management, particularly in urban tunnels, is considered as a part of the ventilation system design. The goal is to see the environmental impacts beforehand. From environmental aspects, preventive measures are required either inside or outside the tunnel in some cases. Niayesh tunnel in Tehran is taken as a case for proving the objectives presented in this study. Concentration of carbon monoxide at the vicinity of the portals is calculated using the proper dispersion simulation. The results of dispersion modeling for the assumed worst case of ventilation can help to understand the environmental impact of ventilation. The worst traffic emissions for a congested traffic scenario,are selected as an emission source for dispersion modeling. According to the traffic condition and fleet composition, the crucial emission extracted from the tunnel is carbon monoxide. Therefore, the performed simulation only focuses on carbon monoxide dispersion modeling. From the other side, carbon monoxide is taken as a demonstration pollutant, because it is inert and chemical reactions can be neglected in short-term considerations. A lagrangian model composed of Graz Lagrangian Model and Graz Mesoscale Model is used for flow-field and dispersion calculations.

KEYWORDS: *Dispersion modeling; Graz Lagrangian Model (GRAL); Graz Mesoscale Model (GRAMM); Tunnel ventilation; Tunnel pollutant; Tunnel portal.*

INTRODUCTION

Niayesh is an urban tunnel located at the northern part of Tehran. The tunnel with unidirectional traffic is a connection link between western and eastern parts to create a west-east highway. The twin bore tunnels with lengths of about 2.8 and 2.6 km have 2-lane traffic in north and south tubes, respectively. Moreover, it provides an access from/to the north-south Kordestan highway. Hence, the north and south tunnels have respectively two and one exit portals which discharge polluted air to the environment. The regular cross section area of the tunnel (an average value) is about 85 m^2. A longitudinal ventilation system is employed for normal and fire operation of the Niayesh tunnel. An air exchange system has been implemented in the middle of the tunnel. Air exchange is considered to be used in specific situations, such as congested traffic with three lanes or other in-tunnel air quality problems, and to extract hot smoke (Rafiei, 2016) or ventilation control (Sturm *at el.,* 2017) in a fire incident. Urban road tunnels are known as an appropriate solution for traffic flow by opening traffic nodes and creating network connections particularly in large cities (Broere, 2015). At the same time, tunnels can lead to the environmental problems which are the

---

*Corresponding Author Email: *mehdierafiei@gmail.com*
Tel.: +9823 33654040 Fax: +9823 33654040

Note: Discussion period for this manuscript open until October 1, 2018 on GJESM website at the “Show Article”.

consequences of discharge of centralized tunnel pollutant sat portals or other air exchange locations i.e. shafts. Therefore, very careful investigation of environmental impacts (on human health, ecology, etc.) must be considered as the main component of tunnel designing process in general and the environmental assessment study (EAS) in particular (Cowie *et al*. 2012a , 2012 b ; Kuykendall *et al.* 2009; PIARC, 2008; Rafiei, 2016). A practical suggestion dealing with such kind of environmental issues and minimizing the negative effects of the discharged pollutants are the main objectives. In case that the polluted air has a negative effect, the problem should be solved during the tunnel design. Gorla *et al.* (2008) have carried out a simulation investigation on portal air pollution and its environmental impacts. The solution is to transmit the polluted air of the tunnel to a location far from the portal area. Such kind of solutions are widely implemented in road tunnel all over the world and their useful related information can be found in CETU (Centre for Tunnel Studies) and PIARC (Permanent International Association of Road Congresses) publications. Another solution is to discharge the polluted air into the higher levels using high stacks at tunnel portals or air exchange locations (Brandt 2009; Capon *et al.*, 2008; Riess, 2009). Any of mentioned solutions can add up to the high costs of ventilation system and tunnel construction. However, ignoring such solutions may create the environmental problems which can make tunnel operation impossible. These issues are critical to the environmental studies and are assumed among the reasons that environmental consideration is required for designing the tunnel networks. As mentioned before, Niayesh tunnel has two separate ventilation systems. In the longitudinal ventilation, pollutants are discharged into the portal areas. Due to the distance of the portals from the residential areas, the influence of tunnel pollutants on the surrounding areas at portals can be considerable. However, longitudinal ventilation system is at the first priority and the other system is only used in emergency cases. Therefore, the focus in this study is on dispersion modeling in the portals rather than stacks. In case of dealing with environmental issues in the portal area, air exchange system can be used to solve the problem. Due to the importance of the subject and environmental sensitivities, air quality management at tunnels and portals is one of the attractive issues for researchers all over the world. Uhrner *et al.* (2017) investigated the distribution of NOx around the tunnel portals and a canyon street in Germany. The aim of their micro-scale simulation study was to calculate traffic emissions inside the tunnel and to calculate dispersion of NOx around the street and tunnel portal. Some practical solutions to traffic problems are proposed for air quality management at the vicinity of the portal. In another experimental study, Colberg *et al*. (2005) focused on air pollution in two different tunnels with different traffic situation and tunnel geometry. They mainly focused on particle measurements inside the two different tunnels. They also focused on aerosol measurements and emission factors estimation mainly for PM10 and $PM_{2.5}$ in different locations of the tunnel with various intervals. Uhrner *et al.* (2016) experimentally studied the in-tunnel air quality measurements for non-exhaust emission calculations and attempted to measure the non-exhaust PM10 deposition in tunnel. Bruno *et al*. (2005) reported the result of pollutant dispersion simulation and comparison of the results with the experimental measurements (1995) around the southern portal of the Landy tunnel in Paris. In this simulation study, a scale model was developed for dispersion modeling. The results of their simulation and experimental measurements showed the specified consistency, but some other problems were highlighted due to the complexity of the dispersion phenomenon. Ottel *et al.* (2002) developed a simple Lagrangian model for dispersion modeling. Ottel *et al*. (2003 a) compared the simple GRAL model with JH-Model. In 2005, the model was evaluated in Austria, Japan, and the capability of the software was proven through the reasonable outcomes for different tunnel portals (Ottel *et al*., 2005). After development of the GRAL model and various experimental evaluations, comparisons were also made with CFD. Sanchez *et al.* (2017) developed the CFD model to calculate NOx in an urban network with high traffic in Madrid, Spain. Employment of such CFD models for simulation of dispersion in the large scale cases, such as the current case study and the one studied by Sanchez *et al.* (2017), is not feasible (Ottel *et al*., 2002 and 2003). The reason is that consideration of weather conditions will be a big challenge for simulation. Therefore, the model was limited and simplified for several days (Sanchez *et al.* 2017). Rollings (2017) made a comparison between the result of GRAL and CFD models for a wind field in a complex urban canyon environment in a limited scale with simplified boundary conditions. The outcome showed the proper performance of the GRAL model, though a small difference was observed near the facade of the buildings. Dong *et al.* (2017) performed a similar CFD simulation in a short tunnel. They mostly attempted to investigate the in-tunnel air quality for CO_2 dispersion. Nowadays, the GRAL/GRAMM models (Graz Lagrangian Model/ Graz Mesoscale Model) are being used all over the world, particularly in the Europe and Austria. The capability of the model is not limited to point dispersion modeling like tunnel portals, as it can be used for line and area dispersion modeling as well (Berchet *et al.*, 2017; Kurz *et al.*, 2014; Öttl, 2012; Öttl *et al.*, 2008; Öttl *et al.*, 2004). GRAL/GRAMM model has been successfully used in Austria and other countries in the world. It is important to know how the GRAL/GRAMM model will work in a mega city like Tehran. For correct implementation of the software, it is necessary to set some important parameters in GRAL/GRAMM domain or even an evaluation study might be required (Ottel *et al*., 2004). However, the GRAL/GRAMM model has been already used in some studies on Tehran. Rafiei (2018) used the GRAL/GRAMM model for traffic pollution dispersion in a relatively large area in Tehran. The results, particularly flow field calculations, showed a very good adaption considering the realities. The mentioned study proved that in case of having a good emission source and meteorological data, good results can be expected. Bakhshizadeh *et al*. (2015) employed the GRAL/GRAMM model for traffic emission dispersion modeling in two important streets in Tehran. The aim of this study was to use different capabilities of the mentioned software, called point source dispersion, to simulate CO concentration around the Niayesh tunnel portals. Air quality management at the vicinity of the portals is considered as an important issue in the tunnel ventilation design. A Lagrangian GRAL/GRAMM model was developed for dispersion modeling. Since long-term measurements were not possible, only dispersion simulation was considered in this study. The short-term simulation results were compared with the relevant measurements for model validation. This study was carried out in the Niayesh tunnel in Tehran, Iran in 2015-2016.

MATERIALS AND METHODS

GRAL/GRAMM model

There are various state-of-the-art techniques which have been developed for dispersion modeling purposes. Models like Gaussian, RANS and Lagrangian dispersion are widely used for dispersion modeling all over the world. However, GRAL/GRAMM model is considered in the current work. The model is, in fact, a combination of using wind field model and Lagrangian dispersion model for simulations. These models are developed for particular dispersion conditions including tunnel portals pollutants and low wind speed (Oettl *at el*., 2003 b).

The basic principle of the Lagrangian models is particle tracking in a three-dimensional space. Eq. 1 is applied to calculate the position of the particles in GRAL.

$$x_{i,new} = x_{i,old} + (\bar{u}_i + u_i^{'}).\Delta t \quad (1)$$

Where, $x_{i,new}$ and $x_{i,old}$ indiacte the new and old positions of particle in the space (i = 1,2,3), repectively; $\bar{u}_i$ is the mean velocity component; $u_i^{'}$ denotaes fluctuating part of velocity due to turbulence of the particle movement; and Δt is time increment.

The model uses a standard wind equation for solving wind power (Eq. 2).

$$u(z) = u(z_a).(\frac{z}{z_a})^{ex} \quad (2)$$

Where, $u(z_a)$ and $u(z)$denote wind speeds at elevation of z_a and z, respectively. The wind profile exponent (ex) varies between 0.2 and 0.4, depending on the weather stability class and roughness of the calculation domain (Oettl *at el*., 2003 b).

Boundary conditions and the data required for model set up

The GRAL/GRAMM model was used to simulate CO dispersion around the portal. The main simulation model had two subsets: ‘flow field model’ called GRAMM, and ‘Lagrangian particles model’ called GRAL for dispersion calculation. These models have been successfully used for environmental studies in complex and local scales in many countries in the world. The main boundaries for this model are emission source, topography, and weather condition within the calculation domain. The boundary condition for the GRAL and GRAMM models is described as follows.

GRAL/GRAMM domain

The exact location of the portals is marked in the GRAL domain (Fig. 1). In this study, all the maps, including tunnel location background, were taken from OpenStreetMap and Contributors. A synoptic weather station (Mehrabad airport) is located at the lowest part of the GRAMM domain with relatively a high distance to the portals. The next synoptic weather station named Geophysics station (Figs. 1 and 3) is located relatively in the middle of the GRAMM domain. The only suitable synoptic weather station was Mehrabad airport where is considered a quite big calculation domain for flow field. Size of the GRAMM domain was approximately 14.5 ×27.5 km with a height of 200 m. The thickness of the first layer was 10 m and flow field was calculated for 15 layers in vertical. The GRAL domain was small (10 ×17 km) as compared to the GRAMM domain (Fig. 1). The size of the GRAL domain was defined to fully cover the tunnel portal areas for pollutant dispersion calculations. The horizontal resolution of the GRAMM domain was 10 m. The vertical thickness

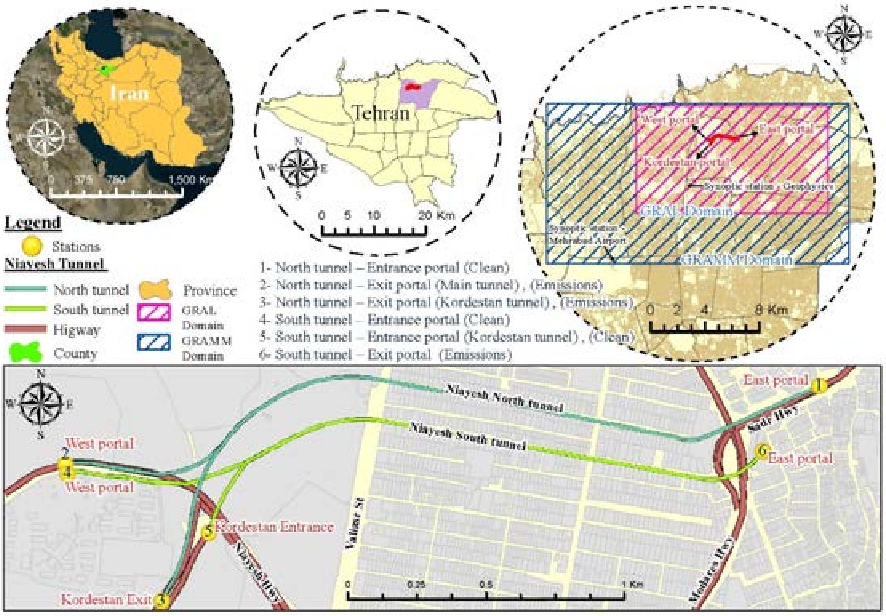
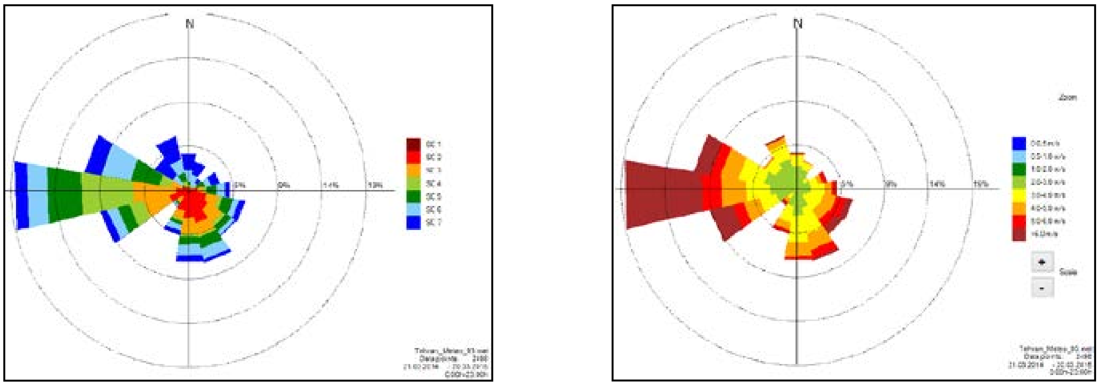


Fig. 1: The study area of Niayesh tunnel portals



a) Wind rose, Mehrabad airport b) Stability class wind rose, Mehrabad airport

Fig. 2: Stability class wind rose (a), wind rose, Mehrabad Airport (b)

of the concentration layer was 1 m. Concentration of CO was calculated in three different heights of 5, 10 and 20 m. For simplicity, the buildings in GRAMM domain were excluded from the calculations. In order to cope with this simplification, a relatively high surface roughness of 1.6 m was chosen. This amount of surface roughness has been already confirmed in a similar flow field calculation in Tehran (Rafiei, 2018). It should be mentioned that the GRAL and GRAMM boundaries, such as resolution, roughness, etc., were defined with respect to the related user manuals.

Topography

Topography of the area is one of the required boundaries for flow field calculation in the GRAMM. The possible resolution of the grid was 30 m. Elevation of tunnel portals area from sea level is between 1430-1460 m.

Wind speed/direction and stability class

Another boundary required for dispersion modeling is weather condition, including the wind speed, direction, and stability class for a period of one year. It means that, in the GRAMM domain, at least one synoptic weather station is required for data collection. As already mentioned, the meteorological data from the Tehran Mehrabad airport synoptic station (Station 1) (Fig. 3) for a period of one year (from March 20, 2014 to March 20, 2015) were used. Fig. 2 shows the wind rose (Fig. 2a) and stability class distribution (Fig. 2b) in the mentioned period. Another synoptic station (Station 2) was also in the calculation domain (Fig. 3). According to Iran's Metrological Organization report (IRIMO), there is only one annual average wind speed for 10 years in Station 2. These data can be used for validation of the flow field results. The main problem for the flow field calculations was relatively poor quality of the input data. In this scale, it is good to have the data for 30 min. or 1 h at least. The data of wind speed and direction were available for each three h. instead of one h. averages or 30 min. The wind speed was not reported for small values. However, considering the available data, the prevailing wind speed and direction were accurately reported in the west direction. Furthermore, the meteorological data covered the congested traffic operating periods very well. Stability class was calculated by the Turner method for each data set (Ashrafi and Hoshyaripour, 2010). These calculations were based on the available data for cloud cover, height and net radiation index. As mentioned before, the quality of the input data was not good enough. Nevertheless, the results for flow field contour were quite close to what is known from the two stations. The average wind speeds in Mehrabad and Geophysics Station were nearly 3 and 2.3 m/s from 2010 to 2014, respectively. Although the meteorological station was very close to the boundary of the GRAMM domain, the obtained results fitted

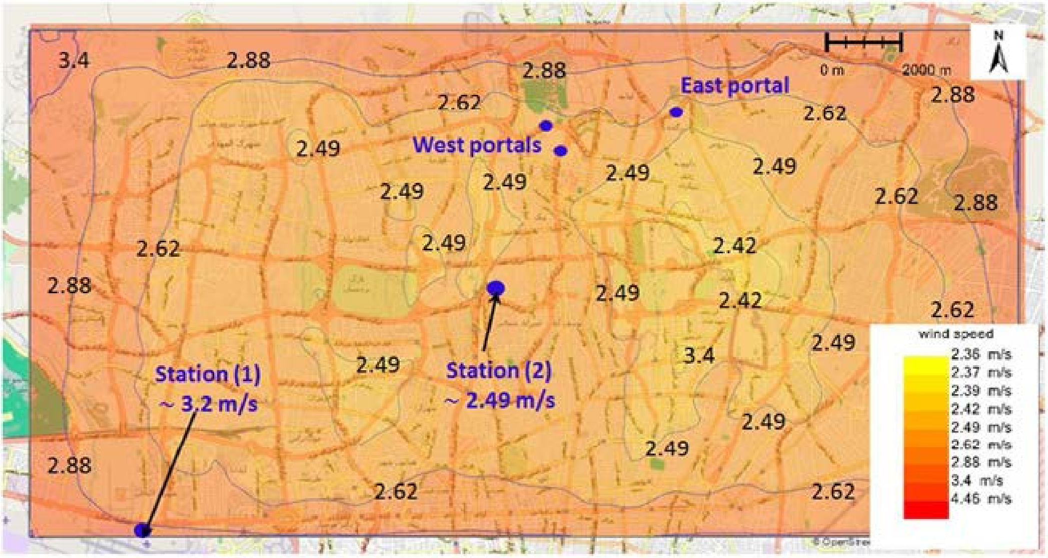


Fig. 3: Flow field contour and annual wind speed in the (1) Mehrabad and (2) Geophysics synoptic stations

quite well to the observations. Fig. 3 depicts the results of the flow field calculation. As it can be seen in the wind speed contour, the average annual wind speeds in the GRAMM domain at the two stations are quite close to the calculated values.

Emission sources–portal emissions

Tunnel portals are applied as an emission source in the GRAL model. Fig. 1 shows the location of the portals, called point sources, in the calculation domain. The source strength for CO (kg/h) was obtained from the ventilation design for the congestion traffic scenario calculations (Rafiei, 2016). For the southern tunnel in congestion traffic, the emitted CO concentration was about 70 µg/m^3 or 61 ppm in 2-lane traffic. In the northern tube, the CO concentration at the end of the main portal was 75 µg/m^3 or 65 ppm, and in the Kordestan end it was 65 µg/m^3 or 56 ppm. Table 1 indicates the extracted volume flow and the corresponding emitted CO per h. These values were used as a point source for portals in the GRAL model.

RESULTS AND DISCUSSION

The contour of mean values for CO concentration in the assumed congested traffic is plotted in Fig. 4. The results are an averaged value for dispersion calculations at the level of 5 m above the ground. The reason for the selection of one-year period is to cover all the possible traffic and weather conditions. According to the results, the maximum values are seen in the portals location with a distance of less than 15 m. Pollutants are discharged from the southern tunnel into the east and from the northern tunnels to the west. The residential buildings are very close to the eastern portal of the southern tunnel (about 50 m) as compared to the northern tunnel portals in the west. A detailed contour of the CO dispersion in the eastern and western portals is shown in Fig. 5. Moreover, Figs. 4 and 5, in fact, similarly show the amount of CO concentration at the level of 5 m at the vicinity of the tunnel portal. The only difference is that Fig. 5 presents a detailed information about the CO concentration with its distance from the portals as well. This has been applied to the 5-m case, as it was

Table 1: Emitted CO from the portals–congestion traffic (Rafiei, 2016)

Tunnel Portal	CO (ppm)	CO (µg/m^3)	Volume flow (m^3/s)	Velocity (m/s)	CO (kg/h)
South	61	69	245	2.88	60
North – main	65	75	200	2.35	54
North – Kordestan	56	65	120	1.4	28

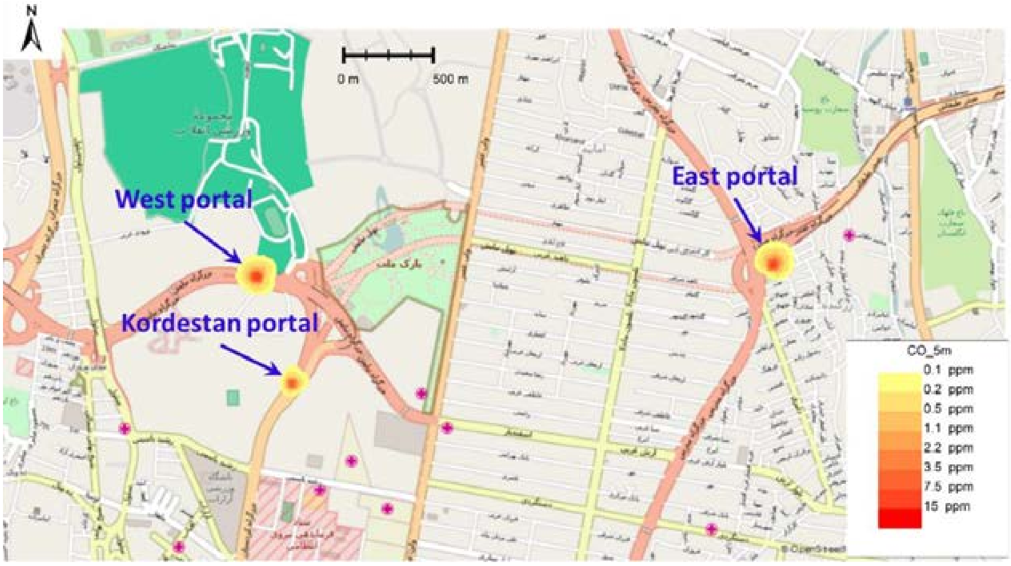
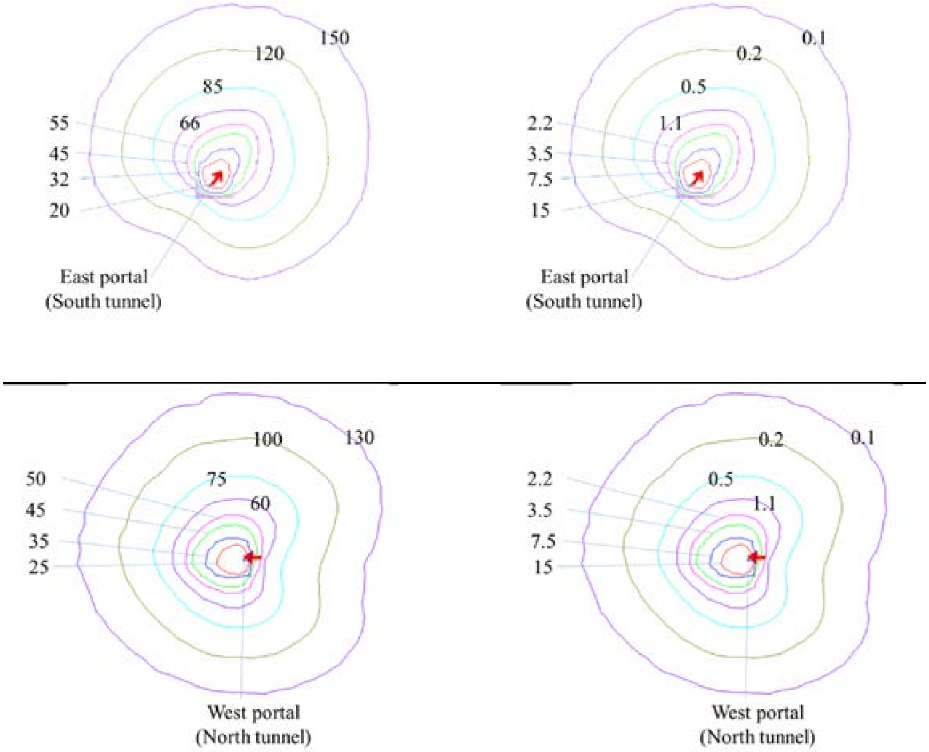


Fig. 4: Mean CO concentration at the Niayesh tunnel portals in congestion traffic–5m

critical compared to others. The pictures in the left (Fig. 5a) and right (Fig. 5b) demonstrate the distances from the portal and CO concentration, respectively. According to the US EPA reports on ambient air quality, which is valid in Iran as well, the CO threshold value in Iran is 9 ppm maximum per one h. and 35 ppm maximum for 8 h. Nevertheless, the CO burdens calculated for the annual mean is not considered as an environmental problem. Furthermore, the ambient or background CO concentration is not considered in dispersion simulation models and the contours are only the results of the dispersion of the CO emitted from the portals. If required, the real ambient value should be added to the results.

The CO emitted from the eastern portal of the southern tunnel, with a velocity of about 2.88 m/s, expanded mostly in the east direction up to a radius of 150 m around the portal. Meanwhile, the CO emitted from the western portal of the northern tunnel, with a velocity of about 2.35 m/s, expanded in the west direction up to a radius of about 130 m from the portal (Fig. 5). This confirms the effect of prevailing wind direction on calculations. The highest CO concentration (15 ppm) was seen in the area with a distance of less than 20 m from the portal. The maximum annual mean of CO concentration of 2.2 ppm is calculated at distance of 50 m from the portal where the residential buildings are located. Considering the direction of CO developments and location of the buildings, the real CO value will be less. In the western portals, CO dispersion contours are shaped circularly. This shape is to some extent different from the shape at the eastern portal. This can be attributed to the fact that the air extracted from the portals with relatively low speed heads against the prevailing west wind. According to the meteorological conditions and prevailing wind speed for Tehran, the wind is mostly in west–east direction. For example in east portal, CO was mostly developed in east direction rather than west direction (Fig. 5). Thus, the shape of the contour, particularly in a region lower than 60 m from the portal, is similar to the ellipse rather than



a) Distance from the portal (m)

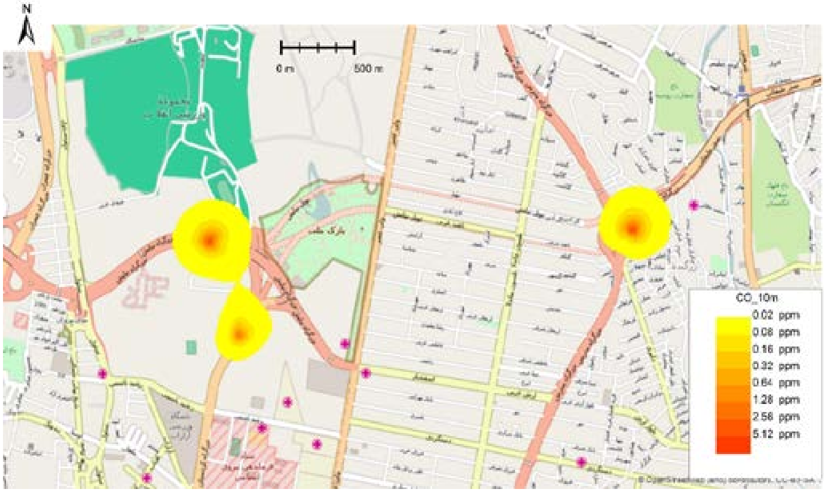
b) CO concentration (ppm)

Fig. 5: Mean CO concentration (ppm) in different layers–5m

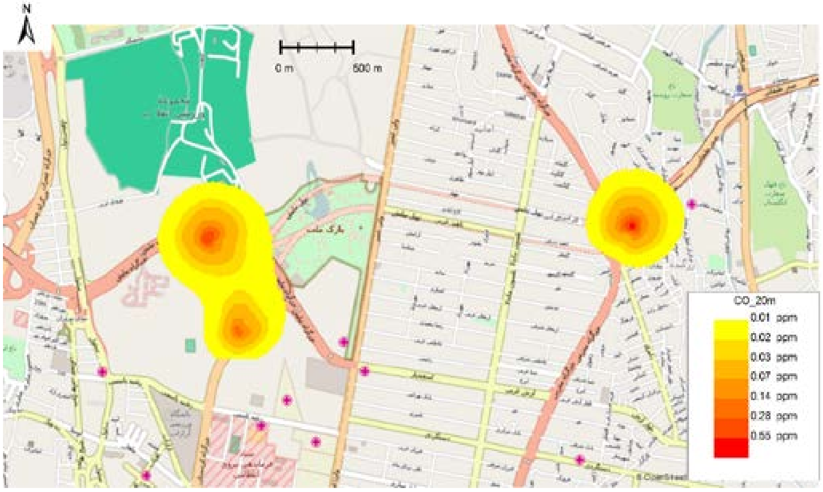
the circle. Meanwhile, in the west portal and in the same distances, the dispersion mostly looks like a circle than an ellipse. This was due to the effect of the prevailing wind speed which was against the tunnel flow. The output velocities of the air extracted from the portals were 2.35 and 1.4 m/s in the main and Kordestan tunnel portals, respectively. Contrary to the eastern portal, there is no residential are close to the western portals. According to the results, the mean CO concentration is calculated as 15 and 7.5 ppm covering distance of about 25 and 35 m in the portal direction. In higher distances, CO concentration level is lower than 4 ppm. Hence, CO pollution levels are not crucial environmentally. Dispersion concentration levels decreased strongly with height at both the eastern and western portals. As shown in Fig. 6a, at the level of 10 m., a reduction of 65% is observed in maximum value. In the higher levels, for example higher than 20 m, CO concentration is close to the ambient value (Fig. 6b).

Model validation by experimental measurements

Short-term measurements were carried out at the tunnel portal in order to evaluate the quality of the ventilation calculation chain including emission modelling, calculation of the air volume flow, and



a) Mean CO concentration at the Niayesh tunnel portals–10 m



b) Mean CO concentration at the Niayesh tunnel portals–20 m

Fig. 6: Mean CO concentration at the Niayesh tunnel portals

dispersion model. The experiment was carried out for a period of one h. (2 to 3 pm) on 5th and 6th of July 2016 at the eastern portal of the southern tunnel of the Niayesh tunnel. The measurement was performed in two different parts: inside at the end of the tunnel and outside at the vicinity of the portal. Inside and outside measurements were considered for ventilation calculation validation and dispersion modeling investigation, respectively. In-tunnel measurements were done by tunnel sensors and at the same time by manual sensors. Outside measurements were carried out using manual sensors. All the sensors have been calibrated inside the tunnel shortly before usage. It should be mentioned that the main objective in this part of the study is not validation of the ventilation system, but investigation of dispersion model for proper model set up. Validation of the ventilation system design has been already done with detail consideration of various scenarios (Rafiei, 2016). However, it is necessary to validate ventilation system, particularly traffic emissions, briefly as well. This will help to prove the calculation of airflow and CO concentration for short-term and long-term congested traffics (Tables 1 and 3). As previously mentioned, long-term measurements were not possible in this study.

CO concentrations at the vicinity of the eastern portal of the southern tunnel

During the measurements, the wind speed at the tunnel area was in the range of 2.6 and 2.8 m/s in west direction, which was very close to the annual prevailing wind speed and direction (Fig. 3). The weather condition was clear, without clouds and mostly stable with temperature of 30-35 °C. The results of one h. average measurements for CO concentration are shown in Table 2. The measurements were done for 5 and 10 m above the ground level at the distances of 10, 20 and 50 m from the southern tunnel portal at the east direction. The results include a background CO concentration of approximately 1-2 ppm.

Traffic density, CO concentration and air flow at the end of the southern tunnel

In addition to CO at the vicinity of the portal, traffic density, CO level and air velocity were measured at the end of the southern tunnel. This experiment was performed in order to validate the emission calculations for traffic and the aerodynamic calculations for tunnel situation. Traffic was moving smoothly during the measuring periods. Total number of the vehicles, which passed the tunnel, was about 4,200 vehicle/ h. and all of them were gasoline fueled passenger cars. Density of the vehicles was 70 vehicle/km (or 35 vehicle/km/lane) in the tunnel. Average air velocity in the tunnel was about 4.5 m/s. For short-term consideration, the averaged cross sectional air velocity was read from the tunnel sensors. Volume flow can be obtained through multiplying the speed by tunnel cross sectional section area. This is a rough estimation method, which is valid only for scenarios with steady traffic and airflow conditions. Many CFD simulations have been carried out to calculate volume flow for several traffic

Table 2: CO concentration around the southern tunnel portal–one h. average measurement

CO concentration at level of 5 m				CO concentration at level of 10 m			
Distance from portal [m]	CO measured [ppm]	Distance from portal [m]	CO simulated [ppm]	Distance from portal [m]	CO measured [ppm]	Distance from portal	CO simulated [ppm]
10	10-12	-	No data calculated	10	4-5	-	No data calculated
20	5-8	24	6.5 + 1*	20	2-3	25	3.5+1*
50	3-4	56	2.5 + 1*	50	1	45	2.5+1*

*1 ppm must be added to simulation results as an ambient CO concentration

Table 3: Comparison of short-term measurements with the ventilation design and calculation, southern tunnel

Item	Design	One h measurement
Air velocity (m/s)	~ 4.8	~ 4.5
CO concentration (ppm)	26	22
Ambient CO (ppm)	1	1
Traffic composition	Totally passenger cars	Totally passenger cars
Traffic speed (km/h)	60	~ 60
Traffic density (vehicle/km/2 lanes)	75	70

scenarios during the ventilation system design (Rafiei, 2016). The output of one of the mentioned scenarios which was the most critical one, is considered as a boundary condition for long-term dispersion modeling (Table 1). The validity of simulations (both tunnel ventilation and dispersion modeling) for one-year studies is confirmed by short-term measurements and simulations. CO concentrations at the beginning and at the end of the tunnel were about 1 and 22 ppm, respectively. Niayesh tunnel ventilation system is using 15 min. averaged values for normal condition control. However, the measurement period for manual sensors and tunnel sensors was chosen to be 1 min. It should be mentioned that shorter periods (e.g., few seconds) can also be selected, but one-min. averaged values were enough in this study. The averaged value was compared to design values as well. Short-term measurements showed similar air velocity and CO concentration at the end of the tunnel, as compared to the ventilation design. These findings confirmed the assumed emission factors for the description of the emission behavior of Tehran's fleet. Table 3 presents more details about the comparison of the simulation or design with the measurements. Close values obtained in the same situation can contribute to verification of the ventilation design and the CO (kg/h) already assumed for congested traffic as well (Rafiei, 2016). The calculation method, equations and software in both moving and congested cases were the same.

Short-term dispersion modeling for the eastern portal of the southern tunnel

A short time air dispersion simulation for the eastern portal of the southern tunnel is carried out considering the above-mentioned meteorological boundary conditions. The ambient CO concentration was assumed to be 1 ppm in calculations. The concentration of CO output from the tunnel portal was about 22 ppm. Velocity of the air extracted from the tunnel portal was about 4.5 m/s (Table 3). This leads to an approximately 35 kg/h CO emission from the tunnel to the portal surrounding areas, which is also used in dispersion simulation. Figs. 7 and 8 show the CO dispersion results around the eastern portal of the southern tunnel, 5m above the ground level in the mentioned short time simulation. According to the results, the maximum CO concentrations at that level are calculated as 6.5 and 2.5 ppm at distances of 24 and 56 m from the portal, respectively. The measured values concerning CO at distances of 20 and 50 m from the portal were 5-8 and 3-4 ppm, respectively (Table 2). Comparison of the measured and simulated results shows a good agreement between them. Expansion of CO along the normal vector to portal, particularly close to portal, confirms the effect of an output air of 4.5 m/s from the tunnel in dispersion. Similarly,

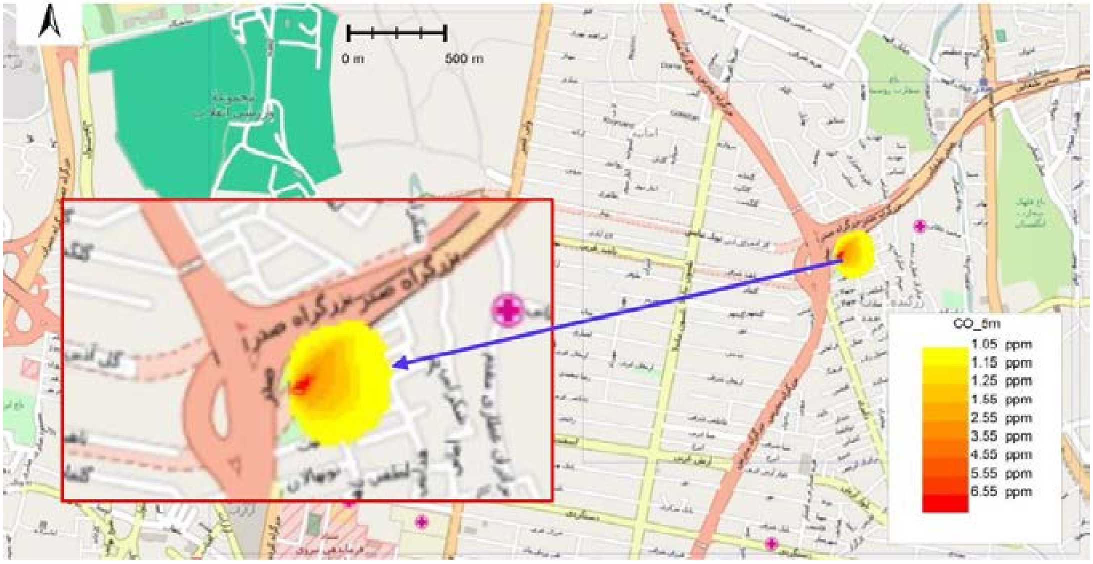
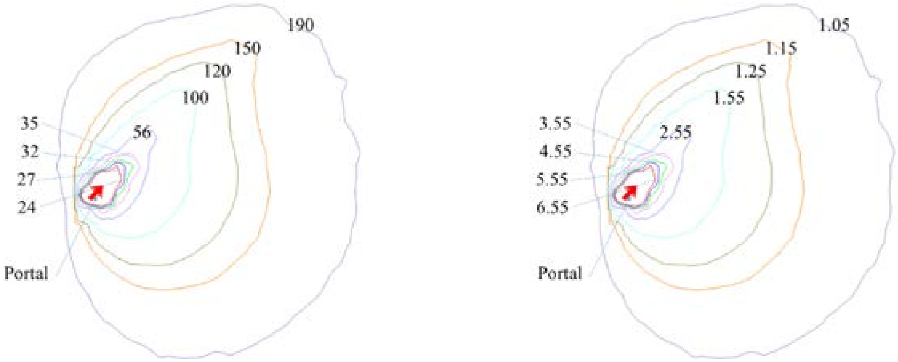


Fig. 7: Mean CO concentration at the eastern portal of the southern tunnel of the Niayesh tunnel for short-time dispersion modeling-5 m

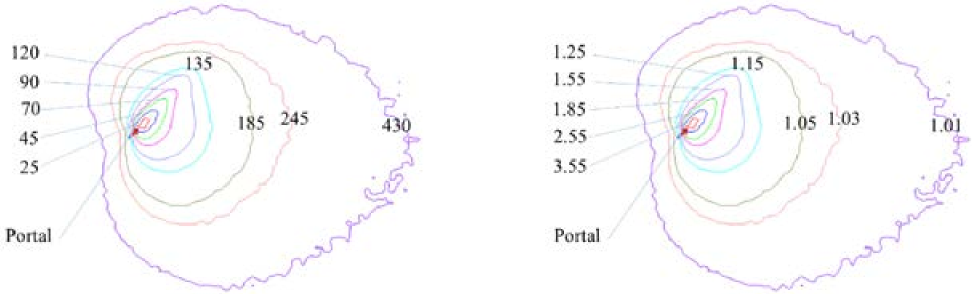
Fig. 9 presents the result of simulation in 10 m above the ground level. In this case, CO concentrations are calculated as 3.5 and 2.5 ppm at distances of 25 and 45 m from the portal, respectively. Meanwhile, the measured values were 2-3 and 1 ppm at distances of 20 and 50 m from the portal, respectively. Comparison of the results from the simulations and measurements for this case also shows a relatively good agreement. The results presented in Fig. 8 evidently show that the output air from the tunnel influences the carbon monoxide dispersion at the area close to the portal and in lower elevation (5 m). The direction of dispersion is



(a) Distance from the portal (m)

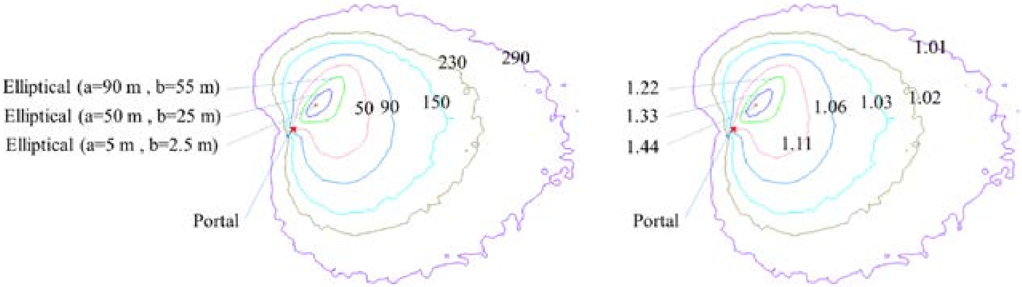
(b) CO concentration (ppm)

Fig. 8: Mean CO concentration at the eastern portal of the southern tunnel of the Niayesh tunnel for short-time dispersion modeling (with detail of distances (a) and CO concentration (b))-5 m



(a) Distance from the portal (m) – 10m

(b) CO concentration (ppm) – 10m



(c) Distance from the portal (m) – 20m

(d) CO concentration (ppm) – 20m

Fig. 9: Mean CO concentration at the eastern portal of the southern tunnel of the Niayesh tunnel for short-time dispersion modeling (with detail of values and distances)

mostly in perpendicular to the tunnel portal up to about 100 m. The simulation results (Table 2) are to some extent higher than the measurement results, because it was not possible to measure the amount of CO at the front of the tunnel portal with presence of traffic (major axis of ellipse in Figs. 8 and 9). Therefore, the measurements were done somewhere in minor axis. Nevertheless, according to the CO contours and taking into account real distances, concentration is very close to measurements with an error of less than 10%. The situation of dispersion was different at the higher distances from the portal (> 100 m), because the prevailing wind speed (mostly in west direction) was the determinant factor in the areas away from the portal. By increasing the monitoring elevation of dispersion to 10 m, (Figs. 9a and b) the effect of airflow from the portal is reduced to approximately 70 m.

Figs. 9c and 9d depicts the CO concentration counter around the portal for 20 m above the ground level. As it can be seen in the dispersion counter (Fig. 9d) and the related distance (Fig. 9c), CO concentration is very low and close to the ambient value. Furthermore, dispersion of the CO at the portal area is mostly in the same situation and three elliptical CO spectrums with center of 50 m away from the portal are observed. With increasing the monitoring altitude from 5 m to 10 and 20 m above the ground level, the CO dispersion direction is changed to the east (Figs. 8 and 9).

CONCLUSION

The aim of this study was to show the possibility of using the GRAL/GRAMM Lagrangian model for pollutant dispersion modelling around the Niayesh tunnel portals. Series of studies are required to evaluate the environmental impact of an urban tunnel. Series of tunnel ventilation studies, including vehicle emission estimation, proper ventilation and control system design, CFD simulations, in-tunnel air quality assessments, and portal dispersion modeling, are interesting topics for researchers all over the world. This study aimed to answer the question that whether a tunnel needs any tunnel air purification or not? The studied tunnel is the first one in Iran, which has been put under the mentioned series of studies. Furthermore, GRAL/GRAMM model has been tested successfully in an area like Tehran. This software is developed for European area, especially Austria. However, the software is being tested in several countries for dispersion modeling, especially traffic in or outside the traffic. The most critical situation of the portal emissions from the ventilation (congested traffic) was selected. The result of dispersion simulations, called long-term for congested traffic mode, showed that the effect of CO dispersion from the tunnel was not remarkable. This did not mean other pollutants can be ignored as another study may be required for each one. Moreover, experimental and simulation investigation was performed on short-term dispersion of the pollutants around the southern tunnel portal. At the same time, validation of the ventilation system calculation was considered. According to the information obtained by experimental measurements and simulation, the results were close to the realty. Finally, this study provides some important information about the CO dispersion at the vicinity of portals. However, the results are obtained for specific conditions, for example meteorological and traffic specifications. An extensive study with long-term measurements is required for exact judgment about the quality of propagation and environmental influence of the tunnel emission.

ACKNOWLEDGMENTS

The aouthors would like to thank Tehran Municipality and Deputy of Technical and Development Affairs and related organizations and companies, consultants and contractors, for facilitating the the required access to documents of the Niayesh tunnel project in this study. The authors are also grateful to Graz University of Technology, particularly the Institute for Internal Combustion Engines and Thermodynamics, for supporting the simulations and softwares.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

CETU	Centre for Tunnel Studies
CFD	Computational fluid dynamics
CO	Carbon monoxide
CO2	Carbon dioxide
EAS	Environmental assessment study
GRAL	Graz Lagrangian Model

GRAMM	Graz Mesoscale Model
IRIMO	Iran Meteorological Organization
JH-Model	Japanese highway public corporation model
h	hour
kg/h	Kilogram per hour
km	Kilometer
m	Meter
min	Minute
m/s	Meter per second
m^2	Square meter
m^3/s	Cubic meter per second
NO	Nitrogen monoxide
NOx	Nitrogen dioxide
PIARC	Permanent International Association of Road Congresses
PM	Particulate matter
ppm	Parts per million
RANS	Reynolds-averaged Navier–Stokes equations
US EPA	United States Environmental Protection Agency
$\mu g/m^3$	Microgram per cubic meter
°C	Temperature in celsius

REFERENCES

Ashrafi, Kh.; Hoshyaripour, A.Gh., (2010). A model to determine atmospheric stability and its correlation with CO concentration. Int. J. Civil Environ. Eng., 2(2): 83-88 **(6 pages).**

Brandt, R.; Riess, I., (2009). Possibilities and limitations of tunnel-air filtration and portal-flow extractions. 13th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, New Brunswick New Jersey, USA: 13-15 May.

Brousse, B.; Vidal, B.; Ponticq, X.; Goupil, Gh.; Alary, R., (2015). Pollution dispersion at an urban motorwaytunnel portal: Comparison of the small-scale predictive studywith the actual conditions measured on the site. Atmos. Environ., 39: 2459–2473 **(18 pages)**.

Berchet, A.; Zink, K.; Oettl, D.; Brunner, J.; Emmenegger, L.; Brunner, D., (2017a). Evaluation of high-resolution GRAMM–GRAL (v15.12/v14.8) NOx simulations over the city of Zürich, Switzerland, Geosci. Model Dev., 10, 3441-3459 **(19 pages)**.

Berchet, A.; Zink, K.; Müller, C.; Öttl, D.; Brunner, J.; Emmenegger, L.; Brunner, D., (2017b). A cost-effective method for simulation city-wide air flow and pollutant dispersion at building resolving scale. Atmos. Environ., 158, 181-196 **(17 pages)**.

Bakhshizadeh, F.; Rezayan, H.; Akbary, M., (2015). 3D Spatio-Temporal Modeling of NOx Air Pollution of Vehicular Traffic in Vali-e-Asr and Fatemi Streets Intersection, Tehran City. Tehran City. Jsaeh., 2 (1): 43-62 **(20 pages).**

Broere, W., (2105). Urban underground space: Solving the problems of today's cities. Tunnell. Undergr. Space Technol., 55: 245–248 **(4 pages).**

Colberg, C.A.; Tona, B.; Catone, G.; Sangiorgio, C.; Stahel, W.A.; Sturm, P.; Staehelin, J., (2005). Statistical analysis of the vehicle pollutant emissions derived from several European road tunnel studies. Atmos. Environ. 39: 2499 –2511 (**13 pages**).

Capon, A.; Sheppeard, V.,;Irvine, K.;Jalaudin,B.; Staff ,M.; Marks,G.; Willmore,A, (2008) . Investigating health effects in a community surrounding a road tunnel stack – a cross sectional study. |Environ. Health. 7: 46 **(10 pages)**.

Cowie, C.T.; Rose, N.; Ezz, W.; Xuan, W.; Cortes-Waterman, A.; Belousova, E.; Toelle, B.G.; Sheppeard,V.; Marks, G.B., (2012). Respiratory Health before and after the Opening of a Road Traffic Tunnel: A Planned Evaluation. PLoS ONE, 7(11): e48921 **(13 pages)**.

Cowie, C.T.; Rose, N.; Gillett, R.; Walter, S.; Marks, GB. (2012). Redistribution of traffic related air pollution associated with a new road tunnel. Environ. Sci. Technol., 46: 2918–2927 **(10 pages).**

Dong, J.; Tao, Y., Xiao,Y.; Tu, J., (2017). Numerical simulation of pollutant dispersion in urban roadway tunnels. J. Comput. Multiphase Flows, 9(1): 26 – 31 **(16 pages).**

Gorla, A.; Gianola,G.; Bettelini,M.; Colombo,L, (2008). Air pollution management for the tunnel Lugano. In: Proceedings of the ITA-AITES World Tunnel Congress. Agra, India Spetember.

Kuykendall, J.R.; Shaw S. L.; Paustenbach, D., Fehling, K.; Kacew, S.; Kabay, V., (2009). Chemicals present in automobile traffic tunnels and the possible community health hazards: A review of the literature, Inhalation Toxicol., 21(9): 747-792 **(46 pages)**.

Kurz, Ch.; Orthofer, R.; Sturm, P.; Kaiser, A.; Uhrner, U.; Reifeltshammer, R.; Rexeis, M., (2014). Projection of the air quality in Vienna between 2005 and 2020 for NO_2 and PM_{10}. Urban Climate., 10: 703-719 **(17 pages)**.

Oettl, D.; Sturm, P.; Bacher, M.; Pretterhofer, G.; Almbauer, R., (2002). A simple model for the dispersion of pollutants from a road tunnel portal, Atmos. Environ., 36: 2943–2953 **(11 pages)**.

Oettl, D.; Sturm, P.; Almbauer, R.; Okamoto,S.; Horiuchi,K., (2003a). Dispersion from road tunnel portals: comparison of twodifferent modelling approaches. Atmos. Environ., 37: 5165–5175 **(11 pages)**.

Oettl, D.; Sturm P.J.; Pretterhofer, G.; Bacher, M.;, Rodler, J.; Almbauer R. A., (2003b). Lagrangian Dispersion Modeling of Vehicular Emissions from a Highway in Complex Terrain. J. Air Waste Manage. Assoc., 53: 1233–1240 **(8 pages).**

Öttl, D.; (2008). Modelling of primary PM_{10} concentrations for the city of Graz, Austria. Cro. Meteorol. J., 43(1): 375-379 **(5 pages)**.

Öttl, D.; Sturm, P.J.; Almbauer, R.A., (2004). Evaluation of GRAL for the pollutant dispersion from a city street tunnel portal at depressed level. Environ. Model Softw., 20: 499-504 **(6 pages)**.

Öttl, D.; Ferrero, E., (2017). A simple model to assess odour hours for regulatory purposes. Atmos. Environ., 155: 162-173 **(12 pages)**.

Öttl, D.; Kropsch, M.; Mandl, M., (2018). Odour assessment in the vicinity of a pig-fattening farm using field inspections (EN 16841-1) and dispersion modelling. Atmos. Environ., 181: 54-60 **(7 pages).**

Oettl, D., (2014). High resolution maps of nitrogen dioxide for the Province of Styria, Austria. Int. J. Environ. Pollut., 54(2-4): 137–146 **(10 pages).**

PIARC, (2008). Road tunnels: a guide to optimising the air quality impact upon the environment. Technical Committee C3.3 Tunnel Operations.

Rafiei, M., (2016). Ventilation and safety of complex tunnel networks in fire cases, Ph.D. dissertation, Institute of thermodynamics and Internal combustion engines. Graz University of Technology publication, Graz, Austria.

Rafiei, M., (2018). Dispersion modelling of Carbon Monoxide Produced by Vehicles - Case Study of Tehran District 2. In 6 th. National Conferecnce of Air Quality Management. Sharif University of Technology, Tehran, Iran, 23-24 January.

Rollings, D.; Parker, N., (2017). Comparison of GRAL wind field with CFD wind fields in a complex urban canyon environment. 23rd Biennal International Clean Air and Environment Conference on the 15-18 October at Pullman Brisbane, 15-18 October.

Sanchez, B.; Santiago, J.; Martilli, A.; Martin, F.; Borge, R.; Quaassdorff, C.; Paz, D., (2017). Modelling NOX concentrations through CFD-RANS in an urban hot-spot using high resolution traffic emissions and meteorology from a mesoscale model. Atmos. Environ., 163: 155-165 **(11 pages).**

Sturm, P.; Beyer, M.; Rafiei, M., (2017). On the problem of ventilation control in case of a tunnel fire event. Case study: Fire Saf.., 7: 36-43 **(8 pages).**

Uhrner, U.; Nöst, T.; Sturm, P., (2016). PM10 non-exhaust emission factors from road tunnel measurements considering deposition and re-suspension, J. Earth Sci. Geotech. Eng., 6 (4): 117-134 **(18 pages).**

Uhrner, U.; Reifeltshammer, R. ; Sturm, P., (2017). Assessment of No$_2$ concentration levels within a street Canyon and tunnel portal micro environment. 18th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Bologna, Italy, 9-12 October.

AUTHOR (S) BIOSKETCHES

Rafiei, M., Ph.D., Assistant Professor, Department of Mechanical Engineering, Semnan Branch, Islamic Azad University, Semnan, Iran and Institute of Internal Combustion Engines and Thermodynamics – IVT, Graz University of Technology, Austria.
Email: *mehdierafiei@gmail.com*

Sturm, P.J., Ph.D., Associate Professor, Institute of Internal Combustion Engines and Thermodynamics – IVT, Graz University of Technology, Austria. Email: *sturm@ivt.tugraz.at*

HOW TO CITE THIS ARTICLE

*Rafiei, M.; Sturm, P.J., (2018). Modeling of carbon monoxide dispersion around the urban tunnel portals. Global J. Environ. Sci. Manage., 4(3): *-*.*

DOI: 10.22034/gjesm.2018.04.03.00*

url: http://gjesm.net/***