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Harmful Gases Profiling in Meru Menora Tunnel using SICK Sensor

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Abstract

This paper discusses the study on the measured harmful gases due to traffic emission in the Meru Menora Tunnel, a Malaysia highway tunnel. The hazardous gasses data would help in promoting essential ventilation system inside the tunnel for the health and safety of the users. The emission gasses concentration reading is divided into two main components comprise of Nitrogen Dioxide (NO2), and Carbon Monoxide (CO). Other than that, the visibility also been measured by using SICK sensor. The measurement has been done during normal, festive and school holiday seasons. Festive season shows the highest number of traffic and thus giving the worst air quality. Ventilation fan system can be activated based on the concentration level of gases and visibility in the tunnel.

Keywords: *Harmful gas, SCADA, Tunnel, SICK sensor, in tunnel ventilation*

1. Introduction

The increasing number of vehicles on the road urged the enhancement of traffic flow and safety especially in heavy traffic highway line. The monitoring system on Meru Menora Tunnel infrastructure due to mountainous landscape on the Malaysia highway line is vital. Diesel emissions spread hazardous gasses that could be harmful to the users. Thus efficient ventilation system is crucial at peak traffic fleet inside the tunnel. In a tunnel, harmful gases can accumulate and became hazardous to the tunnel user and maintenance working staff. Gasses in diesel smoke comprises of Nitrogen Oxides (NOx), Carbon Monoxide (CO), Carbon Dioxide (CO2), Sulfur Dioxide (SO2) and other oxygenated hydrocarbons such as acetaldehyde and formaldehyde [1]. A high concentration can be hazardous particularly in certain circumstances involving traffic collisions where smoke from a small fire can reduce the visibility with possibility of explosion due to the accumulate gasses [2].Therefore, an air ventilation system is needed to reduce the gases concentration in the tunnel to ensure the health and safety of the user. A monitoring system is essential to monitor and determine the gas concentration and visibility in the tunnel. This paper focuses on the harmful gases monitoring inside the Meru Menora Tunnel. The tunnel is located in Northern Malaysia with 861 meter long. It is run in 2 separated tubes; one for north-going traffic and one for south-going traffic, each with two lanes. Figure 1 shows the layout of the Meru Menora Tunnel.

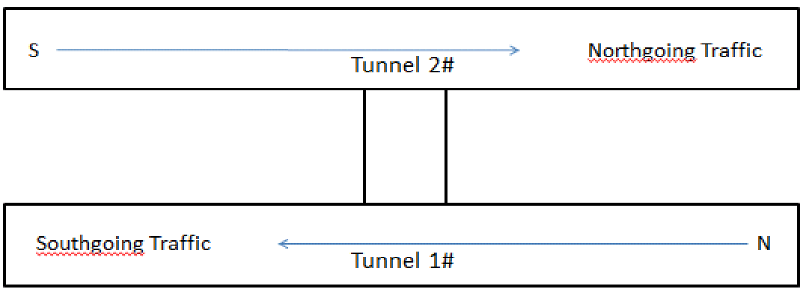

Figure 1. Meru Menora Tunnel layout studied section.

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More than ten momentum ventilation fans are operated at 11kW in each tube to assist the slow traffic or in case of fire. In the tunnel, 15 fire hydrants is provided and equied with 14 ventilation shafts for exhausting polluted air through ventilation fan that is located along north-going tunnel.

2. Data Collection

Monitoring the condition inside the tunnel is vital to ensure the smooth traffic as well as maintaining the safety of the users. For time being the monitoring system is not fully automated. The enhancement of the system can facilitate real time control by the authorities remotely as well as on site. Automated monitoring system can be realized using Supervisory Control and Data Acquisition (SCADA) system. It is defined as a system that operates to monitor, control and analysis the process that generate from various remote devices [3-8]. Programmable Logic Controller (PLC) or Remote Terminal Unit (RTU) acts as data collector and relay the information to the master station for the operator to perform remote control tasks [9-11]. The system required monitoring data and process for further action.

In particular, the harmful gases concentration is the data monitored through the Human Machine Interface (HMI). The data is collected by using SICK sensor that measure the concentration of Nitrogen Dioxide (NO2), Carbon Monoxide (CO) and air visibility. The collected data is used to trigger the ventilation fan to operate and reduce the gasses concentration. An automated ventilation system can minimize the energy consumption with selected fan for ventilations. The gases concentration is determined by using Differential Optical Absorption Spectroscopy (DOAS) where the technique used Ultra Violet (UV) and visible region to analyze broadband spectra transmitted through a long open path [12]. In [12], Beer-Lamberts Law proposed that:

$$I(\lambda,P,T)=I0(\lambda)e-L\sigma(\lambda,P,T)n \quad (1)$$

where

I(λ) = intensities
I0(λ) = unattended reference intensities
L = path length in cm,
(λ) = the wavelength, pressure, temperature dependent absorption cross sections [cm2.molecule-1]
n = denoted as the number density of the species [molecules/cm3].

Equation (2) is proposed by adding Rayleigh and Mie scattering to (1) as both scattering contribute to the radiation extinction, where Equation (2) is as follows:

$$I(\lambda,p,T)=I0(\lambda).exp\{\Sigma[-\sigma jAbs(\lambda,p,T)\times Cj-\varepsilon R(\lambda)-\varepsilon M(\lambda)]\times jL\}.A(\lambda) \quad (2)$$

where $\varepsilon R(\lambda)$ is the Rayleigh extinction coefficient product of Rayleigh cross section, $\boldsymbol{\sigma}$R($\boldsymbol{\lambda}$) and the number density of air, nair. Meanwhile, $\varepsilon(\lambda)$ is Mie extinction coefficient that correspond to $\boldsymbol{\sigma}$M($\boldsymbol{\lambda}$)nair. (λ) is attenuation of the instrument optics while j denote as atmospheric or gas species.

$I0(\lambda)$is determined in open atmosphere and the total cross section $\sigma j(\boldsymbol{\lambda})$ as follow:

$$\sigma jABS=\sigma jS+\sigma j' \quad (3)$$

where σjS is the one slowly varying with wavelength and $\sigma j'$ is the one rapidly varying. After substitute Equation (3) into Equation (2), Equation (4) is produced as:

$$I(\lambda,p,T)=I0(\lambda).exp[-\Sigma\sigma'(\lambda,p,T)\times Cj\times Lj]\ exp\{\Sigma-[\sigma S(\lambda,p,T)\times Cj+\varepsilon R(\lambda)+\varepsilon M(\lambda)]\times jL\}.A(\lambda) \quad (4)$$

Intensity in the absence of differential absorption $I0'$can be estimated using Polynomial fit, Digital smoothing or Fourier transform. Therefore, Equation (4) will turn toEquation (5):

$$I(\lambda,P,T)=I0'(\lambda)exp\ [-\Sigma\sigma'(\lambda,p,T)\times Cj\times Lj] \quad (5)$$

The process of SICK sensor data capturing begin with the laser to shot from sender and receiver. Then the sensor at receiver analyzes the reading and sent the data to converter. Fiber converter at substation panel converts the data and sent it through fiber network straight to Ethernet converter in server room. Next, data is sent through the Ethernet to the SCADA system. From SCADA, fan speed is determined based on the pre-set and the signal is sent to panel in server room. The signal is converted to fiber signal and is sent by using the fiber network to the VSD. After receive the signal, VSD runs the fan at its desired speed and response signal back to SCADA system. Response from VSD is read by SCADA and view new speed of the fan.

Figure 2 presents the configuration of SCADA system test for the sensor. Firstly, VICOTEX sensor sender emit infrared signal to receiver with the right alignment aim to achieve maximum signal strengths with the minimum possible gain setting Then, receiver sensor analyzes the reading and sent it to PLC in current 4-20mA format. After signal is received, the PLC processes the data and sent TCP/IP signal to SCADA system through Local Area Network (LAN). SCADA software will recognize the signal and display on the HMI.

Figure 3 shows the graph conversion from current signal to gas concentration. The graph is constructed by measuring the current signal sent by the sensor and the concentration display on the HMI. As example, when the signal input is 20 mA, the concentration of the gas will be 27648 m. Meanwhile, the minimum current of 4 mA will produce 0 m gas. The current value is analog value from sensor to the PLC.

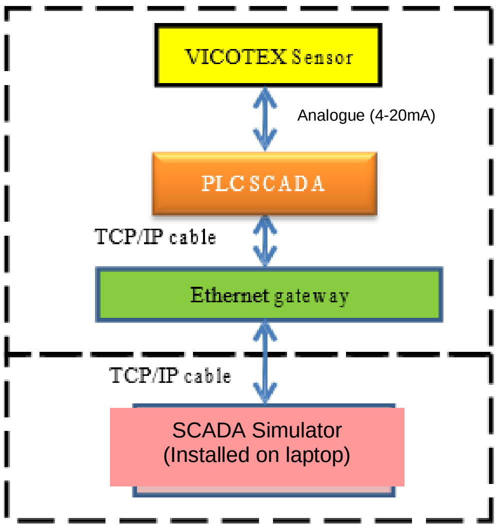

Figure 2. SCADA system test setup

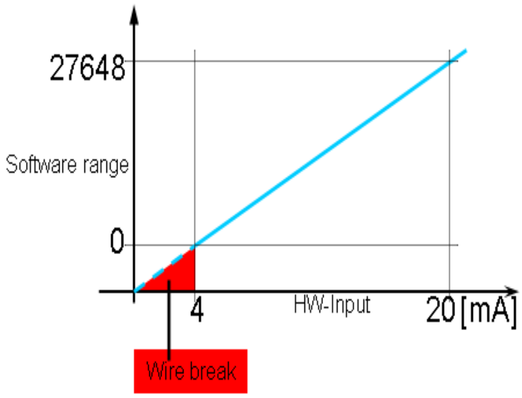

Figure 3. Current signal to gas concentration graph conversion

Table 1 show the value of m produces when we aly the graph on Fig. 4 which is as a reference of connection between Analogue signal (mA) and Output Software. The test kit value shall verify the system functionality by using Tunnel Sensor Control Unit (VICOTEX/TSCU) Utility Software to ensure correct issue and receipt of commands as well as response of the command through status monitoring using SCADA HMI. The value of gases in the Meru Menora Tunnel will simulate analog output using VICONOX/TSCU Utility software to sensor and compare to the reading show in SCADA HMI.

Table 1. Value from test kit

Simulation (mA)	4	%	12	%	20	%
Visibility (m)	1.1	1.1%	55.3	55.3%	100	100%
NO2 (m)	0.2	0.05%	198.6	49%	399.8	100%

CO (m)	43	1.73%	1296.5	52.25%	2481.2	100%

The arrangement of the ventilation fan is shown in Figure 4. Table 2 shows the level set of ventilation fan according to several set points according to the minimum standard value. The levels are divided into 5. Level 0 is the minimum level which operates with 4 fans at 30 Hz frequency speed. Meanwhile, Level 4 mode operates as maximum mode with 12 fans switch on at 45 frequency speed.

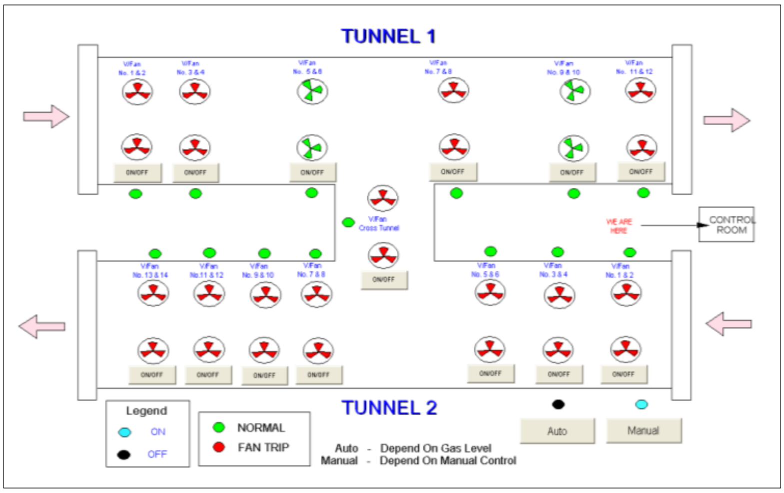

Figure 4. Ventilation fan location in the Meru Menora Tunnel

Table 2. Operation level of ventilation fan

Level	Set Points				
	Visibility (m)	CO (m)	NO_2 (m)	Fan Frequency (Hz)	No. of Fans Active
0	< 2.0	< 20	< 0.5	30	4
1	2.5	20	0.5	35	4
2	5.0	40	1.0	35	7
3	7.5	60	1.5	40	7
4	10.0	80	2.5	45	12

3. Results and Analysis

Table 3 shows the calculated number of vehicles in a week for Normal, Festive and School Holiday season respectively. The Festive season recorded the highest total vehicles followed by School Holiday, while Normal shows the lowest number.

At peak Festive season, the air quality is expected to be the worst as the number of vehicles is more than usual. The air quality in term of visibility and gasses concentration is shown in Figure 5. The most harmful NO_2 gas shows an extremely low reading while visibility reading is at 3 ± 1 m. The CO gas is average at 5 m, however increased by 10 m in the afternoon. Thus, 4 fans at the speed of 35 Hz is activated for ventilation purposes. The ventilation is hoped to reduce the gasses concentration, thus reducing the risk of fire, explosion, and gas poisoning as well as increasing the visibility.

Figure 6 shows the comparison of visibility during Normal, Festive and School Holiday season. The visibility in Normal condition is less than 0.5 m since the vehicles flow through the Meru Menora Tunnel is less compared to School Holiday season. The traffic is increased during School holiday in both direction, North and South-going. Thus, the visibility reading increased around 1.5 m. Meanwhile, in Festive season, the heavy traffic increased the reading up to 2 m.

Table 3. Total vehicles for Normal, Festive and School Holiday Season respectively

Day	SEASON		
	Normal	Festive	School Holiday
1	20057	22293	21601
2	22041	27022	25418
3	21685	29516	24490
4	19179	28661	20416
5	19076	34758	21685
6	20494	36306	21506
7	19214	25863	22315
TOTAL	141746	204419	157431

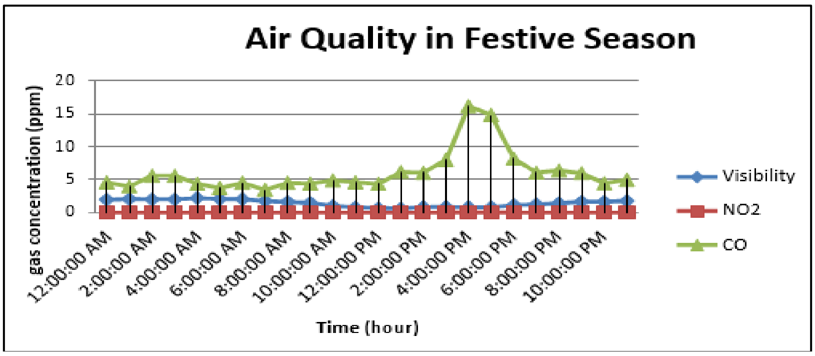

Figure 5. Air Qualities for Festive Season

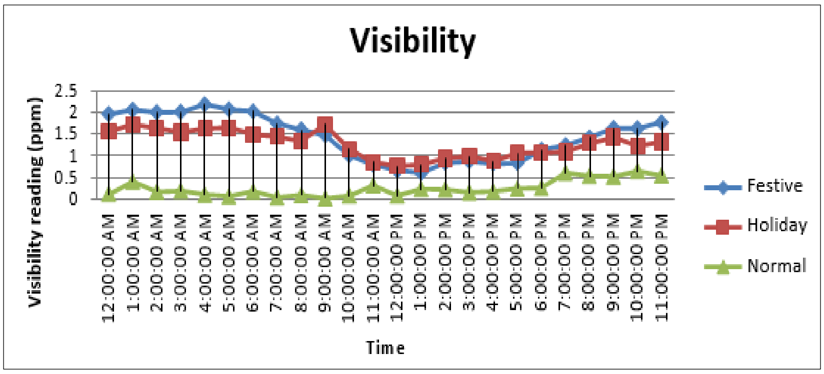

Figure 6. Visibility comparison during Festive, Holiday and Normal season

Nitrogen Dioxide (NO_2) gas reading is shown in Figure 7. The reading is less than 0.002 m for both Normal and School Holiday season. For Festive season, it can be observed that the NO2 gas reading is increased up to 0.016 m due to the heavy traffic. As the time flow, the vehicle flow also increase, thus, the harmful gas also increase and reduce the gas concentration helps the tunnel user drive safely.

Comparison of Carbon Monoxide (CO) gas concentration is illustrated in Figure 8. In Normal season, the reading is less than 4 m meanwhile in School Holiday; the reading shows that the CO gas concentration is less than 6 m. However, there is slightly increment between 5-7 am which recorded 11 m reading. In Festive season, the gas concentration is highest at 16 m measured at 4 pm and recorded 15 m at 5 pm. The reading shows that the ventilation fan helps to reduce the gas concentration.

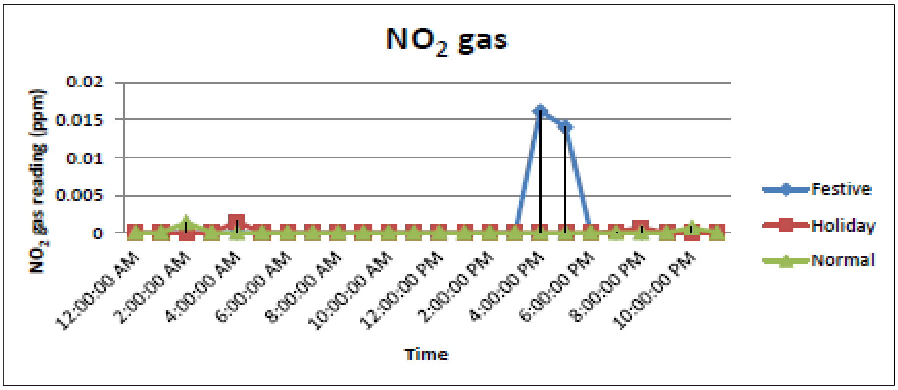

Figure 7. Nitrogen Dioxide (NO2) gas concentration reading comparison

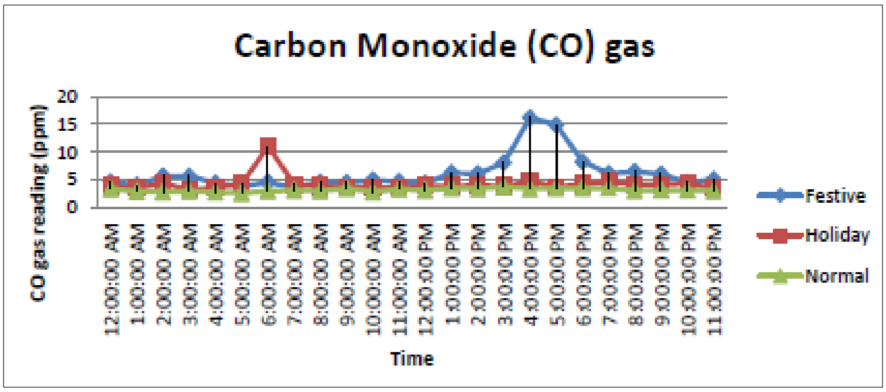

Figure 8. Comparison of Carbon Monoxide (CO) gas concentration reading.

Figure 9 presents the fan speed for Festive, Holiday and Normal season. The fan speed is simulated based on Table 2 and input from measured visibility, NO2 and CO gas shows in Figure 6, 7 and 8, respectively. In Figure 9, measured gas during festive season simulate varies fan speed from 12 am to 9 am. As example, at 12 am, the fan speed is at 30 Hz and increase to 35 Hz when time increase to 1 am. Meanwhile, the fan speed from 3 to 6 am is nearly constant about 35 Hz. Besides, from 9 am to 11 pm, the fan speed is constant a minimum 30 Hz. Holiday and Normal season shows constant fan speed at 30 Hz. Based on the fan speed simulation, the increase number of vehicles during Festive season increase the gas concentration. Thus, increase the fan speed.

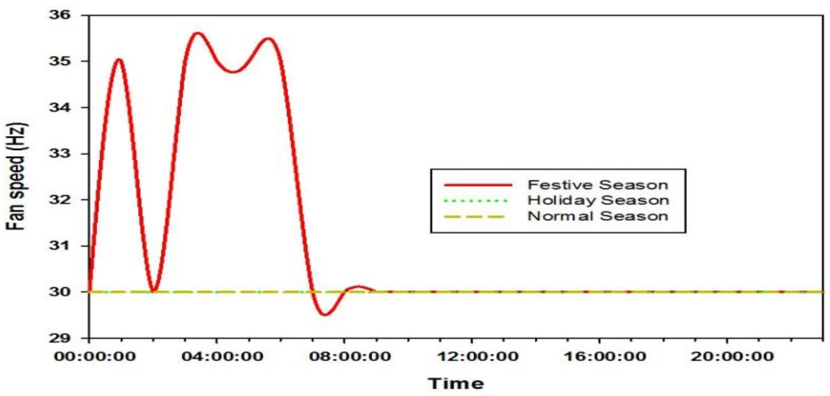

Figure 9. Simulated fan speed of festive, holiday and normal season

4. Conclusion

The air quality inside the Meru Menora Tunnel in term of visibility, CO gas and NO2 gas are measured and analysed to promote essential ventilation for health and safety purposes. The ventilation fan system in Meru Menora Tunnel also discussed. The fan system will operate depending on the gasses concentration level, thus not all fan are operated at one time. This will encourage an efficient power consuming by selecting certain fan configuration at certain frequency. Data on total vehicles shows that Festive season is highest compared to Normal and School Holiday season. Besides, the fan speed also increases due to the increase of vehicle during Festive season. Therefore, the gasses concentration is the highest during Festive season compared to other season. It is expected to have a better ventilation system during Festive season when the traffic is high.

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