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Analytical Method to Compute Air Demand for Pollution Control in Modern Road Tunnels

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***Abstract*— When sizing of Tunnel Ventilation Air demand, of late it is a common practice to size the Ventilation Fan for Emergency Fire scenario such that the velocity inside the tunnel is greater than the critical velocity corresponding to the fuel HRR (Heat Release Rate). However, in urban traffic, the sizing of ventilation system must be assessed for both Emergency fire scenario as well as the congested traffic conditions because the air demand to control the pollution level inside the tunnel can be higher than that for Emergency fire case. This report aims to arrive at the air demand required to control the pollution (CO Carbon Monoxide, NO_2 Nitrogen Dioxide and Opacity) inside a 10 km long tunnel and a traffic flux of 1000 vehicles per hour using Analytical approach and discusses the critical parameters which affects the Air Demand.**

***Keywords*—Air Demand, CO (Carbon Monoxide), NO_x (Nitrogen Oxide), Opacity, PCG (Passenger Car – Gasoline), PCD (Passenger Car – Diesel), PCU (Passenger Car Unit), HGV (Heavy Goods Vehicle).**

I. INTRODUCTION

Tunnel ventilation systems should provide adequate in-tunnel air quality during normal and congested traffic operations, support the management of portal emissions and self-evacuation and rescue efforts during emergency incidents. For the design and dimensioning of the Ventilation system, following thresholds for the air quality are used;

- CO = 70 ppm,
- NO_2= 1 ppm
- Opacity = 0.005 m^{-1}

II. PROBLEM STATEMENT

Considering a single lane urban road tunnel of 10 km length at an altitude of 1000m with +4% gradient. The tunnel has a traffic flux of 1000 vehicles per hour. The design traffic speed is 60 km per hour and during congestion, the traffic speed is 10 km/hr. The traffic distribution is 10% HGVs, 54% PCG and 36% PCD. The average mass of HGV is 25t. The tunnel is planned to open to public on the year 2025. This is considered as the base model.

III. ANALYTICAL APPROACH PROCEDURE

A. Time mean number of vehicles

The number of vehicles of a particular category n_{cat} in a tunnel section is calculated based on equation (1).

$$n_{cat} = D.L_{sec}.a_{cat} \qquad (1)$$

$$D = \frac{q}{v} \qquad (2)$$

where L_{sec} is the section length, D is the traffic density (vehicles/km), and a_{cat} is the proportion of that vehicle category. The traffic density D is calculated from the PCU density using equation (2), or from the traffic flux, q (veh/h), and speed, v (km/h).

Based on the formulae (1) & (2), the number of vehicles for PCG, PCD & HGV are 90, 60 & 16.7 respectively. Table (I) shows the summary.

TABLE I. TIME MEAN NUMBER OF VEHICLES

Category	Table Column Head					
	q	***v***	***D***	***L***	a_{cat}	n_{cat}
PCG	1000	60	16.7	10	0.54	**90**
PCG	1000	60	16.7	10	0.36	**60**
HGV	1000	60	16.7	10	0.1	**16.7**

B. Emission Rates

The base emission rate g_{cat} quantifies the vehicle-specific tailpipe emission for a specific pollutant as a function of average vehicle speed and road gradient. The factor differs for gasoline and diesel fuelled cars. Table (II) to Table (XII) shows the base emission rates of CO, NO_x and Opacity and Particulate matter (PM) for PCG, PCD and HGV.

Corresponding to a design speed of 60 km/hr and a gradient of +4, the CO emission rate (g/hr) for PCG, PCD and HGV from Table (II), (III) & (IV) are 37.8, 3 and 62.3 g/hr respectively.

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TABLE II. BASE EMISSION RATES FOR CO - PCG

PC Gasoline CO [g/h] 2018							
V	***Gradient %***						
km/h	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	5.4	5.4	5.4	5.4	5.4	5.4	5.4
10	7.7	8.8	9.7	11.0	12.0	14.1	16.6
20	8.4	10.2	12.6	15.5	22.7	35.4	50.2
30	7.7	9.3	11.1	13.7	17.3	22.8	31.1
40	8.3	10.3	12.9	16.4	22.3	33.2	48.9
50	8.9	11.8	14.0	18.2	23.8	33.1	46.7
60	8.5	11.4	13.3	18.2	25.3	**37.8**	59.2
70	9.9	13.3	17.9	25.6	36.4	60.4	109.0
80	12.5	16.2	21.1	31.0	49.8	89.1	166.2
90	11.7	15.7	22.7	35.6	67.5	146.1	264.3
100	15.5	20.9	31.6	50.4	85.9	209.4	415.7
110	26.7	33.2	47.4	78.1	148.6	326.2	791.2
120	47.2	54.9	74.1	130.7	259.8	604.4	1506.2
130	85.3	106.2	142.2	236.6	504.3	1318	2568.7

TABLE III. BASE EMISSION RATES FOR CO - PCD

PC Diesel CO [g/h] 2018							
V	***Gradient %***						
Km/h	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	0.3	0.3	0.3	0.3	0.3	0.3	0.3
10	0.8	0.9	1.1	1.3	1.5	1.8	2.0
20	0.9	1.0	1.3	2.8	3.3	3.6	4.1
30	0.9	1.2	1.4	2.4	3.0	3.5	3.9
40	0.9	1.2	1.4	2.0	2.7	3.2	3.7
50	1.0	1.1	1.4	1.8	2.6	3.1	3.6
60	1.0	1.1	1.2	1.6	2.4	**3.0**	3.6
70	1.0	1.1	1.2	1.6	2.1	2.8	3.4
80	0.9	1.1	1.2	1.6	2.1	2.4	3.2
90	0.9	1.0	1.2	1.5	1.9	2.1	2.9
100	1.0	1.1	1.2	1.3	1.6	1.9	2.7
110	1.2	1.2	1.2	1.4	1.5	1.7	2.5
120	1.3	1.3	1.2	1.4	1.8	2.0	2.8
130	1.4	1.4	1.2	1.4	2.0	2.4	2.9

TABLE IV. BASE EMISSION RATES FOR CO - HGV

HGV Diesel CO [g/h] 2018							
V	***Gradient %***						
Km/ h	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	3.8	3.8	3.8	3.8	3.8	3.8	3.8
10	11.7	14.1	17.3	21.0	24.3	28.0	31.3
20	10.0	11.4	17.8	22.3	26.2	30.6	35.2
30	8.7	10.1	18.3	23.9	30.6	37.8	42.3
40	5.8	8.7	18.8	26.9	37.3	48.1	55.1
50	4.1	6.2	19.3	29.4	43.2	56.8	64.8
60	3.5	6.1	19.8	34.9	53.3	**62.3**	67.7
70	3.6	6.1	20.3	40.3	63.1	67.8	70.6
80	3.6	6.1	20.7	45.8	73.3	77.2	76.6
90	3.6	6.1	22.2	47.0	75.7	83.1	82.4
100	3.6	6.1	22.3	49.6	78.1	88.6	88.0

Corresponding to a design speed of 60 km/hr and a gradient of +4, the NO_x emission rate (g/hr) for PCG, PCD and HGV from Table (V), (VI) & (VII) are 6.9, 51 and 247.5 g/hr respectively.

TABLE V. BASE EMISSION RATES FOR NO_x - PCG

PC Gasoline NO_x [g/h] 2018							
V	***Gradient %***						
Km/h	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	0.2	0.2	0.2	0.2	0.2	0.2	0.2
10	1.2	1.3	1.6	1.8	2.1	2.3	2.6
20	1.3	1.6	2.0	2.4	2.9	3.4	4.2
30	1.3	1.6	2.1	2.7	3.4	4.3	5.4
40	1.4	1.8	2.4	3.1	4.1	5.1	6.2
50	1.3	1.7	2.3	3.2	4.3	5.5	7.1
60	1.3	1.8	2.5	3.6	5.1	**6.9**	8.6
70	1.3	1.9	2.7	4.0	5.9	8.3	10.1
80	1.4	2.1	3.2	5.2	7.4	9.8	12.3
90	1.6	2.4	3.7	6.4	9.9	11.8	14.6
100	1.9	3.0	4.4	7.7	12.1	15.3	17.8
110	2.6	3.8	6.0	9.2	13.9	18.3	22.5
120	3.4	5.0	8.2	12.2	16.3	21.7	26.4
130	4.4	7.2	13	17.9	19.8	24.7	29.7

TABLE VI. BASE EMISSION RATES FOR NO_x - PCD

PC Diesel NO_x [g/h] 2018							
V	***Gradient %***						
Km/h	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	4.5	4.5	4.5	4.5	4.5	4.5	4.5
10	7.7	9.0	10.3	12.2	14.5	16.9	19.9
20	7.9	9.5	11.6	14.7	18.4	23.1	28.4
30	8.0	10.1	12.8	17.3	22.4	29.3	36.9
40	8.0	10.2	13.5	19.0	25.8	34.8	45.8
50	8.0	10.4	14.2	20.6	29.2	40.2	54.7
60	8.4	11.3	16.2	23.9	35.2	**51.0**	71.6
70	8.7	12.4	18.7	28.9	43.6	63.0	87.8
80	7.6	11.9	20.0	34.0	56.7	88.8	126.6
90	8.3	13.3	24.5	43.9	70.0	108.6	171.6
100	9.6	14.2	27.0	50.9	86.7	131.1	204.2
110	13.3	21.9	37.9	68.5	114.3	178.8	247.4
120	19.3	32.4	53.2	86.2	142.7	239.2	316.1
130	25.4	47.9	77.1	120.9	191.6	291.5	373.4

TABLE VII. BASE EMISSION RATES FOR NO_x - HGV

HGV Diesel NO_x [g/h] 2018							
V	***Gradient %***						
km/hr	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	14.4	14.4	14.4	14.4	14.4	14.4	14.4
10	54.2	65.7	77.2	86.5	92.7	98.4	103.8
20	41.0	55.3	76.2	88.7	98.8	104.1	111.7
30	32.4	48.5	75.2	92.7	103.1	111.0	127.6
40	23.9	41.6	69.3	105.3	119.2	141.2	174.9
50	20.0	33.1	64.2	111.8	129.8	167.1	211.7
60	16.2	24.5	62.2	122.9	182.0	**247.5**	301.9
70	12.3	16.3	57.5	134.0	234.2	328.0	392.1
80	12.3	16.3	57.5	145.1	286.5	408.4	482.3
90	12.3	16.3	57.5	146.6	294.6	419.5	485.4
100	12.3	16.3	57.5	151.7	304.6	428.6	488.5

Corresponding to a design speed of 60 km/hr and a gradient of +4, the Opacity emission rate (m^2/hr) for PCG, PCD and HGV from Table (VIII), (IX) & (X) are 0.6, 4.9 and 19.3 m^2/hr respectively

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TABLE VIII. BASE EMISSION RATES FOR OPACITY - PCG

PC Gasoline Opacity exhaust [m²/h] 2018							
V	***Gradient %***						
Km/h	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.1	0.1	0.1	0.1	0.2	0.2	0.2
20	0.1	0.1	0.1	0.2	0.2	0.2	0.3
30	0.1	0.1	0.1	0.2	0.2	0.3	0.4
40	0.2	0.2	0.2	0.2	0.3	0.4	0.5
50	0.2	0.2	0.2	0.2	0.3	0.4	0.6
60	0.2	0.2	0.2	0.3	0.4	**0.6**	0.9
70	0.2	0.2	0.3	0.3	0.5	0.9	1.5
80	0.2	0.3	0.3	0.5	0.8	1.3	2.4
90	0.3	0.3	0.3	0.6	1.2	2.1	3.8
100	0.5	0.3	0.4	0.7	1.5	2.9	4.9
110	0.7	0.6	0.7	1.1	2.0	3.7	6.2
120	1.0	0.9	1.3	2.0	3.3	5.0	8.0
130	1.3	1.6	2.3	3.7	5.8	7.9	10.4

TABLE IX. BASE EMISSION RATES FOR OPACITY - PCD

PC Diesel Opacity exhaust [m²/h] 2018							
V	***Gradient %***						
Km/h	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	0.4	0.4	0.4	0.4	0.4	0.4	0.4
10	1.1	1.2	1.3	1.5	1.6	1.8	2.0
20	1.1	1.3	1.5	1.8	2.0	2.3	2.7
30	1.1	1.4	1.6	2.0	2.3	2.7	3.1
40	1.2	1.4	1.8	2.3	2.8	3.4	4.0
50	1.2	1.5	2.0	2.7	3.4	4.2	4.8
60	1.3	1.6	2.1	2.8	3.8	**4.9**	6.0
70	1.3	1.8	2.5	3.2	4.3	5.3	7.0
80	1.3	1.9	2.8	3.8	5.3	6.6	8.6
90	1.5	2.2	3.2	4.6	6.5	8.2	9.7
100	2.0	2.6	3.8	5.6	7.6	9.4	10.6
110	2.7	3.5	4.7	6.6	8.9	10.5	11.7
120	3.4	4.6	6.3	7.9	9.6	11.2	12.5
130	4.3	6.2	8.1	9.9	11.1	12.6	14.1

TABLE X. BASE EMISSION RATES FOR OPACITY - HGV

HGV Diesel Opacity exhaust [m²/h] 2018							
V	***Gradient %***						
Km/h	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**
0	1.8	1.8	1.8	1.8	1.8	1.8	1.8
10	4.3	4.9	5.6	6.3	7.1	7.9	8.6
20	3.7	4.3	5.6	6.5	7.4	8.5	9.6
30	3.5	4.1	5.6	6.8	8.4	9.9	11.3
40	3.3	3.9	5.8	8.0	10.5	12.9	15.0
50	3.1	3.7	5.8	8.6	11.9	14.9	17.5
60	3.1	3.7	6.0	9.3	14.3	**19.3**	22.6
70	3.1	3.8	6.3	10.1	16.7	23.6	27.7
80	3.3	3.7	6.6	12.3	19.4	28.0	32.8
90	3.5	3.9	6.6	14.4	21.7	28.5	33.1
100	3.5	3.9	6.8	15.0	23.0	29.4	33.3
0	1.8	1.8	1.8	1.8	1.8	1.8	1.8
10	4.3	4.9	5.6	6.3	7.1	7.9	8.6
20	3.7	4.3	5.6	6.5	7.4	8.5	9.6

Corresponding to a design speed of 60 km/hr and unidirectional traffic, the Particulate matter emission rate (m^2/hr) for PCG, PCD and HGV from Table (XI) & (XII) are 3.9, 3.9 and 26.5 m^2/hr respectively

TABLE XI. BASE EMISSION RATES FOR NON-EXHAUST PARTICULATES (OPACITY) – PCG & PCD

PC Opacity non-exhaust [m²/h]		
V (Km/h)	***Bi-directional***	***Unidirectional***
0	0	0
10	1.1	0.7
20	2.2	1.3
30	3.4	2.0
40	4.5	2.6
50	5.6	3.3
60	6.7	**3.9**
70	7.8	4.6
80	9.0	5.3
90	10.1	5.9
100	11.2	6.6
110	12.3	7.2
120	13.4	7.9

TABLE XII. BASE EMISSION RATES FOR NON-EXHAUST PARTICULATES (OPACITY) – HGV

HGV Opacity non-exhaust [m²/h]		
V (Km/h)	***Bi-directional***	***Unidirectional***
0	0	0
10	5.1	4.4
20	10.1	8.8
30	15.2	13.3
40	20.2	17.7
50	25.3	22.1
60	30.3	**26.5**
70	35.4	30.9
80	40.4	35.3
90	45.5	39.8
100	50.6	44.2

C.Influence Factor

The base emission rate has to be multiplied with influencing factors and the number of total vehicles to get the total emission rate. Following are the influencing factors to be considered;

Time factor

The emissions databases Table (II) to (XII) have been derived for the year 2018. Use of data for future design years therefore requires a time factor. Table (XIII) & (XIV) shows the time factor for PC & HGV respectively.

Corresponding to design year of 2025,

- The time factor for PCG for CO, NO_x and Opacity is 0.78, 0.62 and 0.95 respectively.
- The time factor for PCD for CO, NO_x and Opacity is 0.8, 0.51 and 0.44 respectively.
- The time factor for HGV for CO, NO_x and Opacity is 0.76, 0.34 and 0.92 respectively.

TABLE XIII. TIME FACTOR FOR PASSENGER CARS, TECHNOLOGY STANDARD A

f_t	**CO**		NO_x		**Opacity**	
PC	**PCG**	**PCD**	**PCG**	**PCD**	**PCG**	**PCD**
2018	1	1	1	1	1	1
2020	0.91	0.92	0.85	0.87	0.98	0.76
2025	**0.78**	**0.80**	**0.62**	**0.51**	**0.95**	**0.44**
2030	0.71	0.74	0.50	0.32	0.93	0.33
2035	0.69	0.72	0.46	0.26	0.92	0.31

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TABLE XIV. TIME FACTOR FOR YEARS OTHER THAN THE BASE YEAR, HEAVY GOODS VEHICLES, TECHNOLOGY STANDARD A

Year	CO	NO_x	Opacity
2018	1	1	1
2020	0.89	0.71	0.96
2025	**0.76**	**0.34**	**0.92**
2030	0.72	0.22	0.91
2035	0.72	0.22	0.91

Altitude factor

The altitude influence on the different exhaust components varies with the type of engine. For example, passenger cars with catalytic converters behave quite differently to cars without such converters. Table (XV) shows the altitude factor for PC at an altitude of 2000 m. For altitude up to 1000 m and for HGVs the altitude has no influence on the emission rates. Corresponding to 1000m altitude, the altitude factor is 1 for both PC and HGVs

TABLE XV. ALTITUDE FACTOR FOR PASSENGER CARS, TECHNOLOGY STANDARD A

f_h	CO		NO_x		Opacity
PC	PCG	PCD	PCG	PCD	PCD
2018	2.0	1.0	1.0	1.0	1.0
2020	1.6	1.0	1.0	1.0	1.0
2025 and later	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**

Mass factor

HGV emissions highly depend on their mass. The emissions data provided in Table (XVI) correspond to a fleet-averaged HGV (representing a combination of light trucks, regular trucks and semi-trailers, buses) with a reference mass of 23 t. Corresponding to 25t HGV, the mass factor for CO, NO_x and Opacity is 1.044.

TABLE XVI. MASS FACTORS (FM)

Type	CO	NOX	Opacity
15 t (e.g. single lorry, bus)	0.9	0.9	0.9
23 t (average)*	1.0	1.0	1.0
32 t (Lorry-trailer combination/semitrailer)	1.2	1.2	1.2
* Average consists of 21% single lorries and 79% truck/trailer or semi-trailer combinations			

The total emission rate G_{tot} (g/hr) considering the influencing factors is shown in Table (XVII).

TOTAL EMISSION RATE – CO, NOX & OPACITY

Category	G_{base}	f_t	f_h	f_m	E	n	G_{tot} g/hr
PCG - CO	37.8	0.78	1		29	90	2654
PCD - CO	3	0.8	1		2	60	144
HGV - CO	62.3	0.76	1	1.04	47	17	789
PCG - Nox	6.9	0.62	1		4	90	385
PCD - Nox	51	0.51	1		26	60	1561
HGV - Nox	247.5	0.44	1	1	109	17	1815
PCG - Opacity	0.6	0.95	1		1	90	51
PCD - Opacity	4.9	0.44	1		2	60	129
HGV-Opacity	19.3	0.92	1	1	18	17	296
PCG - PM	3.9	1	1		4	90	351
PCD - PM	3.9	1	1		4	60	234
HGV - PM	26.5	1	1	1	27	17	442

The total emission of CO, NO_2 and Opacity from the tailpipe of vehicles inside the tunnel is 3587 g/hr, 3761 g/hr and 1503 m2/hr respectively.

D.Fresh Air Demand

The required airflow rate for emission dilution can be calculated by dividing the overall pollution generation rate by the allowable change in air pollutant concentration

$$Q = \frac{G_{tun}}{C_{adm} - C_{amb}} \quad (3)$$

For visibility criteria, the same formula is used in which the concentration C is replaced by the extinction coefficient K, where:

Q = Required fresh-air flow rate [m³/s]

G_{tun} = Total emissions generation rate of the pollutant of interest along the relevant tunnel chainage, [g/s] for gases, [m²/s] for visibility

C_{adm} = Admissible concentration level [g/m³]

C_{amb} = Pollutant concentration in the fresh air (typically drawn from outside the tunnel) [g/m³]

K_{adm} = Admissible level for extinction coefficient (visibility) $[m^{-1}]$

K_{amb} = Ambient level for extinction coefficient (visibility) $[m^{-1}]$

Pollutant concentration can be converted from ppm to g/m³ using below formula;

(mg/m³) = 0.0409 x (ppm) x molecular weight (4)

Fresh Air Demand - CO

For an admissible concentration of CO of 70 ppm.

Concentration CO (mg/m³) = 0.0409 x 70 ppm x 28.01 g/mol = 80.2 mg/m3 = 0.08 g/m³

Q_{CO} = 3587 / (0.08-0) = 44837 m³/hr = 12 m³/s

Fresh Air Demand – NO2

For an admissible concentration of NO_2 of 1 ppm

Concentration NO_2 (mg/m3) = 0.0409 x 1 ppm x 46.01 g/mol = 1.9 mg/ m³= 0.0019 g/m3

Considering an average Oxidation rate of NO_x as 20%

Q_{NO2}=3761x0.2 /(0.0019-0) =395895 m3/hr = 109 m3/s

Fresh Air Demand – Opacity

For an admissible Opacity of 0.005 m^{-1}

$Q_{Opacity}$= 1503/(0.005-0) = 300600 m³//hr = 84 m³/s

IV RESULT & DISCUSSION

The fresh air demand for CO, NO_2 and Opacity for the given Base model tunnel is 12, 109 and 84 m³/s respectively. For the given traffic of 1000 veh/km and 10 km Tunnel, Air demand for CO, NO_2 & Opacity is arrived for following cases;

Positive Gradient (+4%)

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- Traffic consisting of only PC-G
- Traffic consisting of only PC-D
- Traffic consisting of only HGV

Negative Gradient (-4%)

- Traffic consisting of only PC-G
- Traffic consisting of only PC-D
- Traffic consisting of only HGV

By varying the traffic type, the Air demand is compared with the base model. It is to be noted that for HGVs the base emission is available up to a speed of 100 Km/hr. Practically the speed of HGVs is limited to100 Km/hr for safety reasons. Hence the Air demand for HGV alone arrived up to a speed of 100 Km/hr. Figure (1) to (6) shows the results of above cases.

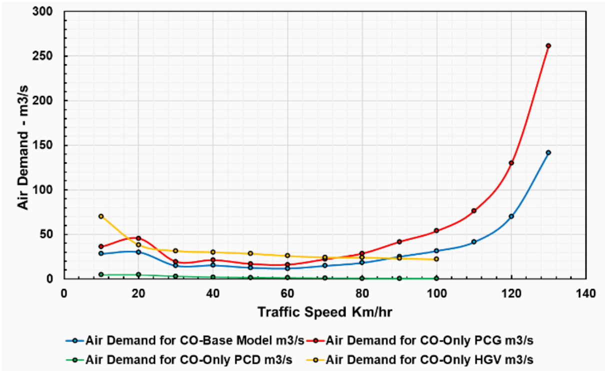

Fig. 1. Air Demand for CO – Positive Slope

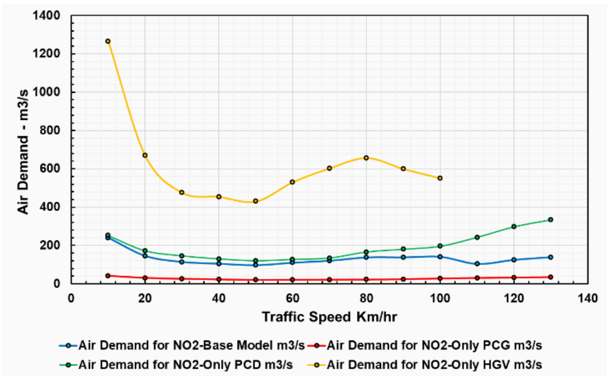

Fig. 2. Air Demand for NO2 – Positive Slope

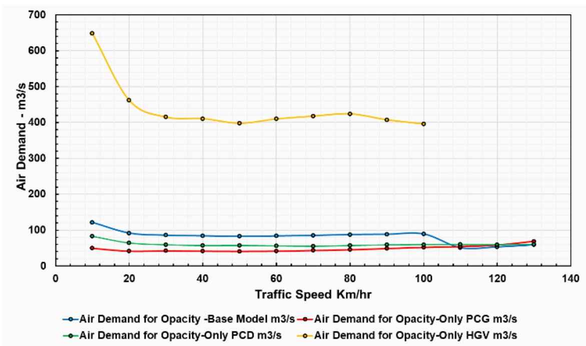

Fig. 3. Air Demand for Opacity – Positive Slope

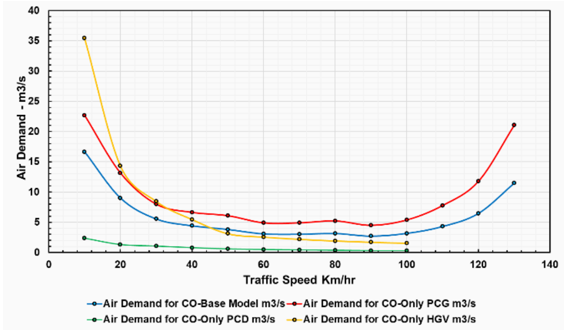

Fig. 4. Air Demand for CO – Negative Slope

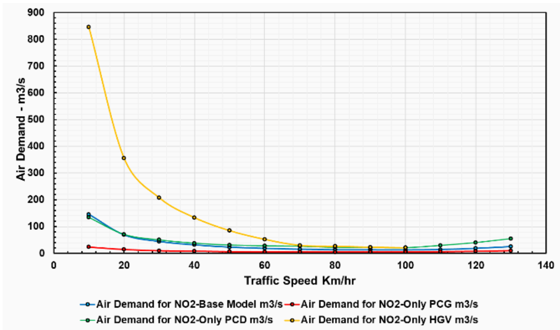

Fig. 5. Air Demand for NO2 – Negative Slope

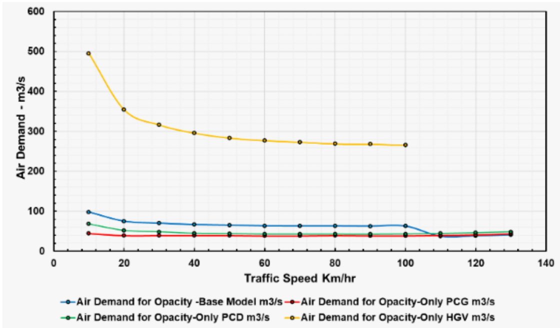

Fig. 6. Air Demand for Opacity – Negative Slope

From Figure (1) to (6), following are the observations;

For Traffic speeds above 80 Km/hr;

- PC-G contributes highest CO emission.
- PC-D contributes the lowest emission of CO.
- HGV contributes highest Opacity & NO_x emission.
- PC-G contributes the lowest NO_2.
- PC-G & PC-D equally contributes low Opacity.
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For Traffic speeds below 20 Km/hr (Congested);

- HGV contributes highest CO, Opacity & NO_x emission.
- PC-D contributes the lowest emission of CO.
- PC-G contributes the lowest emission of NO_2 & $Opacity$.

Emission rate of CO, Opacity & NO_2 is lower when the traffic moves in negative slope (downhill) when compared with emission in positive slope (uphill). This is as expected since more Engine power is required uphill than downhill and hence more emission moving uphill.

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Sizing of the Tunnel ventilation for Pollution control mainly depends on NO_2 and least on CO. NO_x to NO_2 conversion factor thus plays a critical role in the Air Demand required.
For a tunnel with 50 MW HRR, the critical velocity to avoid smoke back layering is 2.7 m/s. The Air demand for Emergency fire scenario considering a Tunnel cross sectional area of 70 m2 is 189 m³/s. It is observed from Fig (1) to (6), there are cases in which the resulting Air demand is more than the fire scenario. This report gives us the basis of choosing the design Air demand for pollution control for different traffic distribution and slopes which will be taken as a benchmark to compare with air demand required to prevent smoke back layering.

REFERENCE

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