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SPEED-DEPENDENT MODELING OF ECOSYSTEM EXPOSURES FROM VEHICLES IN THE NEAR-ROAD ENVIRONMENT

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ABSTRACT

The article presents a model of automobile exhaust emissions in terms of vehicle speed and plant stomatal resistance. The software, which offers several advantages in environmental decision making, has been developed for computing gas—specific flux contributions and total daily ecosystems—health exposure—risk for a near road environment under strong wind conditions. Concentration differential has been taken as proportional to the emission values from vehicles at different speeds. Flux contributions from different gaseous pollutants, and total daily exposure-risks have been computed as a function of vehicular speed and PAR-dependent curvature-coefficient. The calibration and validation of the model will be cost effective, as the number of parameters included in the model is significantly lower than the number required in the conventional models.

INTRODUCTION

Studies on transfer of airborne pollutants to terrestrial surfaces have been primarily concerned with plant receptors that possess photosynthetically active foliage. Vegetation is an important sink for air pollution emanating from several natural and anthropogenic sources. There are various factors that help determine the magnitude of deposition of gaseous pollutants over vegetation at a given height. Among them are wind speed, surface roughness, atmospheric stability, wetness of the exposed surfaces, and stomatal resistance.

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Canopy stomatal resistance, which depends upon several physiological and bioenvironmental factors [1] is one of the most important considerations in gaseous deposition. It influences the uptake of gaseous deposition and is mediated by the degree of turbulent mixing. In particular, under strong wind conditions, aerodynamic resistance can be neglected in comparison to the high stomatal resistance. (For low wind speeds, magnitudes are similar.)

Quantitative estimation of damage contributions from motor vehicles to the near-road environment and sink potential of vegetative canopy are important ingredients of environmental management plans that assess air pollution control strategies. Assessments of area-wise deposition budgets are presently hindered by the inability to compute (or model) gaseous exchange processes with specific vegetation types. An important task under atmosphere-vegetation exchange processes is to develop better methods for quantifying flux contributions and exposure-risks to near road terrestrial environment. Interaction between a gaseous pollutant present in near road environment and a plant receptor is usually expressed using resistance models [2].

In the present article, gaseous emission has been modeled in terms of vehicular speed and integrated with stomatal resistance model [3] for computing gas-specific flux contributions and total daily ecosystem-health [4] exposure-risk for a near road environment under strong wind conditions. Concentration differential has been taken as proportional to the emission values from vehicles at different speeds [5, 6]. Flux contributions from different gaseous pollutants, and total daily exposure risks have been computed as a function of vehicular speed and PAR-dependent curvature-coefficient (PAR = photosynthetically active radiation). Integration has been carried out (over a day) using the Cauchy-Euler method and a time-step of two hours.

THE MODEL

Models for vehicular emissions (Ve) in terms of speed of the vehicle (Vs) have been developed on the basis of data available in [7] for No_x, CO and HC, and are expressed in the following forms:

For NOx

$$Ve\_NOx = 5.6 \times 10^{-4} Vs^2 - 7.1 \times 10^{-2} Vs + 5.75 \qquad (1)$$

For CO

$$Ve\_CO = 1.38 \times 10^{-2} Vs^2 - 2.14\ Vs + 112.0 \qquad (2)$$

For HC

$$Ve\_CO = 1.616 \times 10^{-3} Vs^2 - .288\ Vs + 13.98 \qquad (3)$$

The model works under the assumption of strong wind conditions, and aerodynamic resistance has consequently been neglected in comparison with stomatal resistance. The response of leaf stomatal resistance with respect to PAR is expressed as [3]:

$$Rs = Rsm\,(1.0 + k/PAR) \tag{4}$$

Rsm is minimum stomatal resistance [8-10] under optimal conditions and is expressed as:

$$Rsm = p / (b \times D) \tag{5}$$

where

p = physiological parameter = $4L/(\pi\ a\ N)$ (6)
b = minor length of stomatal opening
L = length of stomatal opening
N = no. of pores per unit leaf area
D = air-gas diffusivity
k = PAR-curvature-coefficient defined as the PAR level at twice the minimum stomatal resistance. Its value has been varied in a given range so as to study the consequent changes in fluxes and exposure-risks.

Flux contributions (F_gas) have been taken to be directly proportional to vehicular emission and inversely to stomatal resistance. Thus they assume the following forms for any of the gases under consideration:

$$F\_gas = Ve\_gas / Rs \tag{7}$$

Total daily ecosystem-health exposure-risk (EHER) for near road environment has been computed as the following integral over time period of a day:

$$EHER = \int_0^{24} n(t) \times F\_gas(t)\, dt \tag{8}$$

Where n(t) is the number of vehicles, and is a function of time (t). It has been assumed to have a normal distribution with its maximum value at 1200 hrs. The following equation most closely reflect this behavior:

$$n(t) = t\,(2265.78 - 94.40 \times t) \tag{9}$$

F_gas also becomes a function of time because two parameters on which it is strongly dependent (Vs and PAR) are both functions of time. Variation of speed has been considered while studying sensitivity [11] of the present model with respect to speed (Figure 1), while PAR has been represented through linear forms ($PAR = 50.0 \times t - 200.0$) with positive and negative slopes in the time-period from 0600 to 1200 hrs and from 1200 to 1800 hrs. For the rest of the time it has been assumed to be zero.

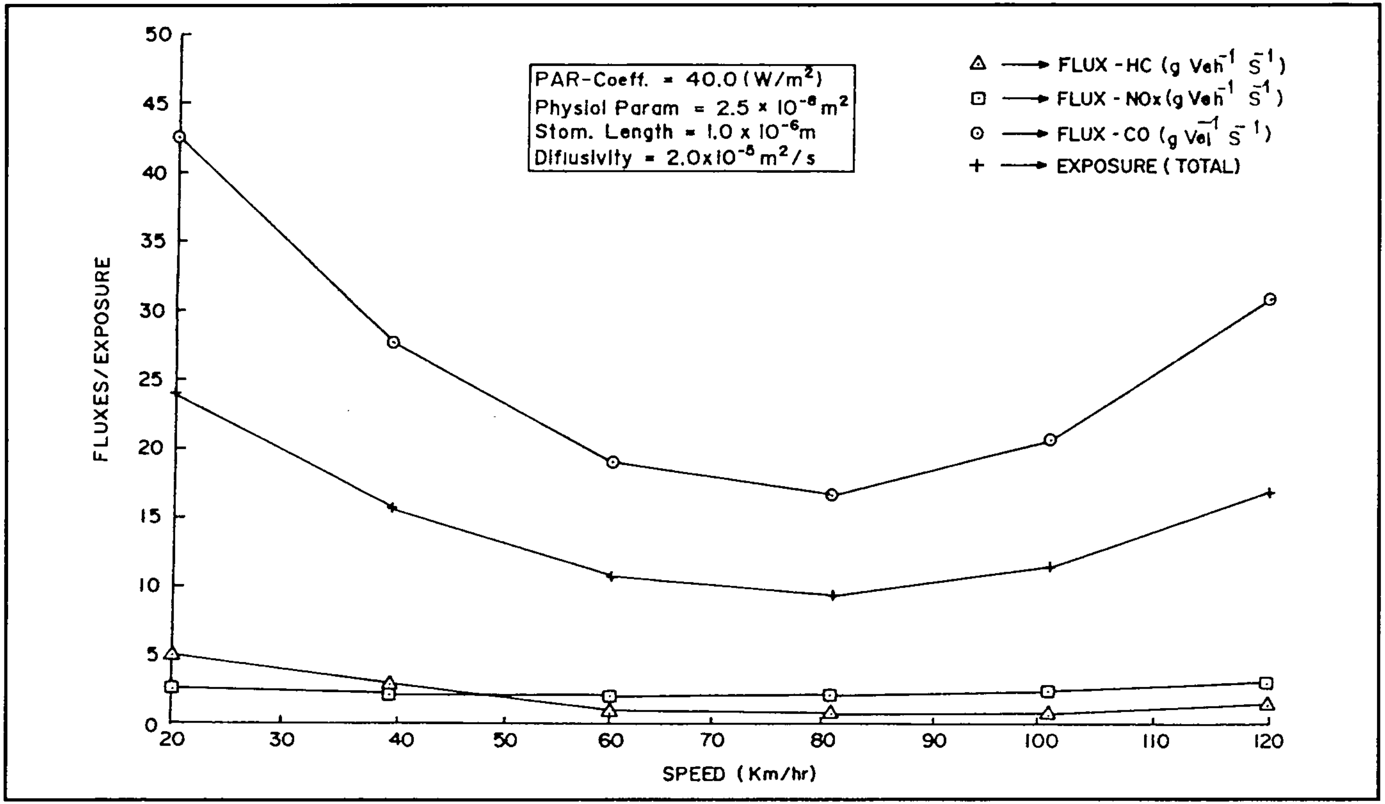

Figure 1. Fluxes for different gases and total exposure w.r.t. speed.

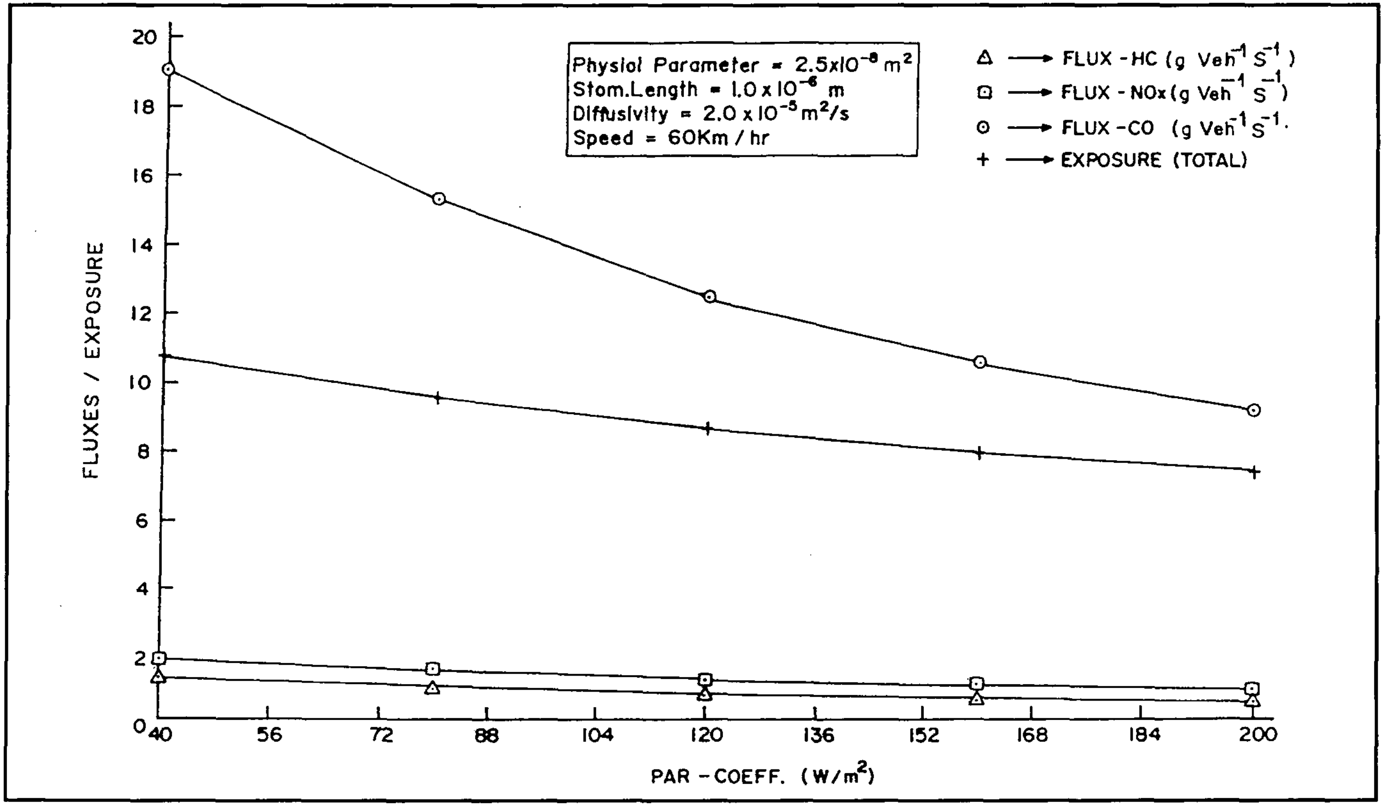

Figure 2. Fluxes for different gases and total exposure w.r.t. PAR-coefficient.

Speed-specific ecosystem—health exposure—risks (Figures 1 and 2) have been computed with recourse to Equation [8]. Expressions for Ve_gas (Equations 1 through 3) have been validated with data presented in Watt Committee Report (Figures 3 and 4).

RESULTS

In order to study the variations in flux contributions from different gases and total terrestrial ecosystem health exposure risk, they have been plotted as functions of speeds of vehicles plying the road (Figure 1) and PAR-Curvature-Coefficient (Figure 2). Comparison of these figures reveals the following salient features:

a) Flux contribution from NOx is highest when the speed is lowest (20 Km/hr).
b) Flux contribution from HC is maximum at the maximum speed (120 Km/hr).
c) Flux from CO is maximum (24 g veh^{-1} s^{-1}) at the speed of 20 Km/hr. As the speed increases, flux contribution decreases till it attains the lowest of 16.6 g veh^{-1} s^{-1} at Vs = 80 km/hr. It rises again as Vs is increased.

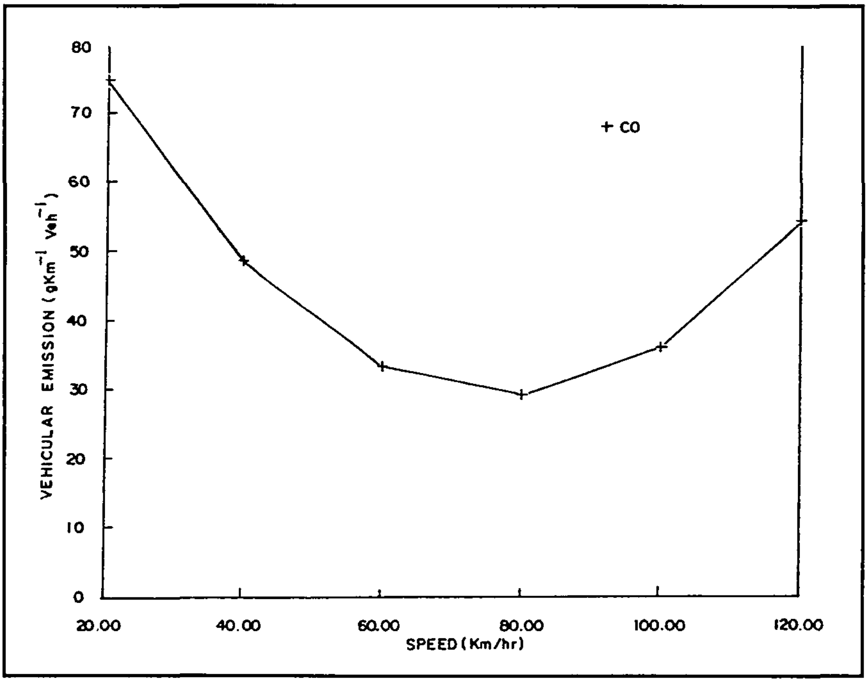

Figure 3. Vehicular emission for CO w.r.t. speed.

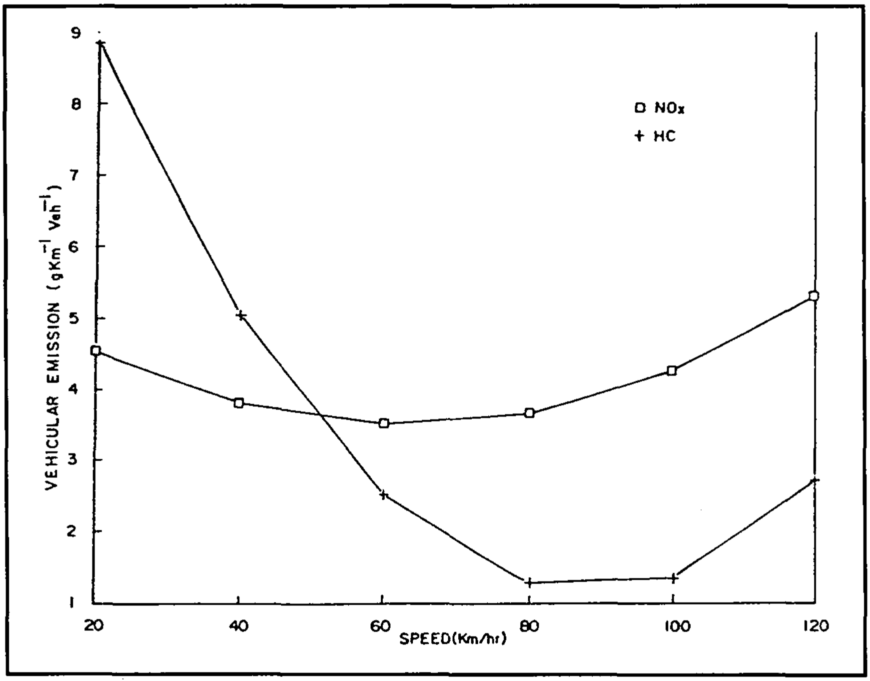

Figure 4. Vehicular emission of NOx and HC w.r.t. speed.

d) Total daily EHER closely follows the flux curve of CO. This can be attributed to the fact that the flux contribution from CO is more than from the combined contributions from NOx and HC.

DISCUSSIONS

A mathematical model should predict well yet be as simple as possible [12]. The present model has several advantages in environmental decision making. The small computational time requirement facilitates faster decision making. Monitoring of parameters becomes highly cost-effective due to the relatively low number of parameters in the model.

Assessments of particulate and gaseous mass transfers within vegetative canopies [13] presents problems due to diurnal, seasonal and spatial variations of various parameters. Also, specific physiological and bioenvironmental controls must be incorporated in the model so as to make it more precise. The present model can be used for the lower and upper speed limits of 20 Km/hr and 120 Km/hr respectively. With little modification, the model can be extended for quantifying region-specific vegetation sink potentials.

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