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Particulate Emissions from Vehicle Travel Over Unpaved Roads

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Background

A number of studies have been conducted to establish emission rates of fugitive dust from vehicular travel on dirt roads. Most of these have shown a relationship between the total amount of dust emitted and variables including soil silt content and vehicle speed. Some have included additional variables such as moisture content and type of vehicle.

A 1973 study by PEDCO—Environmental Specialists, Inc.[1] determined an emissions equation from hi-volume measurement of the form:

$$E = (0.27)\ (1.068)^{x} \qquad (1)$$

E = Dust emissions (lb/vehicle mile)

x = Vehicle speed (mph)

At 30 mph evaluation of this equation shows an emission rate of 1.94 lb/vehicle mile due to vehicle travel. PEDCo then estimated wind erosion from roadways, and apportioned this over the estimated vehicle usage, arriving at a final estimate of 3.7 lb/vehicle mile.

Also in 1973, a study by the Puget Sound Air Pollution Control Agency demonstrated an exponential increase in emissions with vehicle speed[2,3] in the speed range of 10-30 mph. Emissions were found to vary from 3.5 lb/vehicle mile at 10 mph to 22 lb/vehicle mile at 30 mph. Studies of emissions at speeds higher than 30 mph were apparently not determined.

In 1974 Midwest Research Institute (MRI) corroborated the findings of emissions increases in proportion to the square of the vehicle speed for speeds below 30 mph.[4] Between 30 mph and 40 mph the MRI report concluded that the emissions-speed relationship was linear. MRI made the assumption that most travel on dirt roads is at speeds of 30-50 mph, and a linear relationship was derived in the form:

$$e_{roads} = 0.81\ s(S/30) \qquad (2)$$

Where: e = Emission factor (lbs/vehicle mile)

s = Silt content of road surface material (percent)

S = Average vehicle speed (mph)

The results of the MRI study were adapted by the Environmental Protection Agency (EPA) with nationwide applicability for purposes of estimating annual emissions for vehicle travel on dirt roads.[5] The EPA assumed that dirt road emissions were completely suppressed on days with 0.01 inch of rainfall or more. The EPA equation included a correction factor for rainfall data and was published as:

$$E = (0.81)(s)(S/30)\left(\frac{365 - w}{365}\right) \qquad (3)$$

Where: w = Mean annual number of days with 0.01 inch or more of rainfall

Purpose And Method Of Study

Since the EPA emissions estimate method was not developed as a result of investigations conducted in the desert Southwest, and since unpaved roads are believed to be a major contributor to suspended particulate concentrations in this area, a further investigation of these emissions from vehicular travel was timely. An air sampling program to determine emission factors from vehicular travel over unpaved roads in and around Tucson, Arizona was conducted during the summer of 1977. Forty-six measurements were made at five sites in order to re-assess the relationship between particulate emission rates from vehicular travel and variables: vehicular speed, make up of road surface, and moisture.

Standard (GMWT 2200) hi-volume samplers were placed at a height of two meters fifty feet upwind of the road center line to measure upwind background particulate concentrations, and at the same height fifty feet downwind of the road center. The difference in sample collected from the two hi-volume filters was attributed to roadway emissions.

Sampling periods ranged from ten minutes to five hours. During the longer periods normal passing traffic was counted and speeds were estimated by clocking the traffic over measured distances. This afforded data for speeds in the 30-35 mph ranges. In order to get emission measurements for other traffic speeds, one or two vehicles were driven by members of the sampling team, and passed the sampling points repetitively at specified speeds ranging from 10 to 50 mph. It was found that approximately 50 vehicle passes generated sufficient sample for analysis at even the slowest speeds.

Wind speed was measured using a Belfort Model 443 hand held instrument. The sensor height was approximately two meters above the surface. Minimum detectable wind speed was about 0.1 knot and the instrument's accuracy for speed measurements has been reported within +3%, and within +2% for direction measurements. If, during the sample period, the wind direction shifted to more than 45° from perpendicular to the road, sampling activity was terminated. Corrections for wind angles up to 45° were incorporated in the calculations in the manner suggested by Turner.[6]

Nine tests were run using the upwind hi-volume monitor at the usual height and distance, and positioning four samplers on the downwind side at heights of 1, 2, and 3 meters above the ground. Results from these measurements were used as an indicator of the vertical distribution of plume concentration.

Soil surface samples were taken representative of both on-road and off-road soil at nine sample sites. The silt fraction by weight and the percent moisture of each sample were determined by standard laboratory methods.

Near the end of the project, five series of tests were performed with Sierra Impactors in an attempt to determine the size distribution of the particulates sampled, and the rate of deposition of these particulates. The sampler arrangement at this time was comprised of a hi-volume and a Sierra sampler 50 feet from the center line on the upwind side, plus a like pair on the downwind side, plus a Sierra sampler at 150 feet downwind and another at 250 feet downwind from the road center line.

Several problems were noted with the impactor samples during the course of this analysis which did not allow collection of meaningful data. Not all the sample was collected on the ribbon filters, and particulate had collected in easily visible amounts on the supporting metal plates. Additionally, substantial "skipping" of the dry roadway particles was evident, and under microscopic examination, particles as large as 20-30 microns were found on the backup filter, where particles no larger than 0.5 microns should be collected. Similar problems with inertial particle sizing devices have been noted in other recent reports.[7,8]

Results

Make Up Of Road Surface

Surface samples from each test site were collected and the size classified. The silt fraction is that which passes through a 200 mesh screen. These are the particulates less than 74 µm in diameter and represent the fraction of the road surface which easily becomes airborne due to passing vehicles. Road silt was found to vary from 5% through 16%, for an average of 9% at 12 sampling locations.

Surface soil samples were also collected from undisturbed desert adjacent to the test sites, and a considerably higher silt fraction was found. The undisturbed desert contained an average of 2.6 times greater silt fraction than the adjacent road. This would suggest that it would not be good practice to use the percentage silt in area soils maps to estimate roadway silt percentages.

The emission rates found at each test site were plotted against the road silt fraction, and the relationship between emissions and soil surface silt was found to be approximately linear.

Variation Of Emissions With Vehicle Speed

Emissions variation with vehicle speed showed a substantial difference from that which would be predicted by the EPA calculations. Figure 1 shows a plot of emissions data from all five stations adjusted proportionally to 10% silt. Line number 1 is based on the EPA formula.[5] This plots as a straight line and does not fit the experimental curve. If the coefficient in the EPA formula were changed from 0.81 to 0.3 as shown in line 2, then the straight line fits well at 30 mph, but becomes a poorer fit as the speed departs from 30 mph. Curve number 3 makes a better approximation of the experimental data. It is expressed as:

$$E = (\text{silt})\,(c)\,(\text{mph})^2 \qquad (4)$$

Where:
- E = Emission rate (lbs/vehicle mile)
- silt = Silt content of road surface expressed as a fraction
- c = Coefficient = 0.035
- mph = Traffic speed in miles per hour

The principal finding here is that the dust emissions rate varies as square of the speed, rather than directly with the speed supportive of findings of earlier reports.[2, 3, 4]

Method Of Calculation

Studies of emission factor estimates have frequently employed diffusion modeling concepts to estimate source emission strength, although the MRI study employed a mass balance estimation technique.[4] The diffusion technique used in this study was based on the assumption of a continuously emitting infinite line source. Emissions strength is described by the equation:[5]

$$X = \frac{2q}{\sin\phi\,\sqrt{2\pi}\,\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \qquad (5)$$

Where:
- X = Particulate concentration due to road traffic (g/m^3)
- q = Emission rate per length of line source (g/sec-m)
- σ_z = Standard deviation in the vertical of the plume concentration distribution
- u = Wind speed (m/sec)
- ϕ = Angle between wind direction and line source
- H = Effective height of emission (m)

$$q = \frac{(1.25)\,(X)\,(\sigma_z)\,(u)\,(\sin\phi)}{\exp\left[-0.5\left(\frac{H}{\sigma_z}\right)^2\right]}$$

The variables in this equation incorporating the greatest degrees of uncertainty are H, the height of pollutant release, and σ_z. H was measured by comparing the height of the visible dust cloud at the 50 foot downwind sampler with a reference marker, and correlating this height with vehicle speed. Assuming a vertical dispersion stability equivalent to class B (Turner)[8] the dust cloud height at 50 feet was then traced back to the point of origin. The height at the point of origin was then considered to be the effective height of emission. This varied from 0.2 meters (0.7 feet) with 20 miles-per-hour traffic, to 3.2 meters (11 feet) with 50 miles-per-hour traffic. The variation with traffic speed is likely due to the vehicle wake turbulence which increases with speed. This estimate range compares with estimates in other studies[1, 8] where release heights of 1.0 m to 1.4 m were assumed.

The value of σ_z is the standard deviation in the vertical of the plume concentration distribution. If all the conditions for a normal Gaussian distribution were met, then 66% of all values would be found within one standard deviation. As a practical approach it was assumed that at the 50 foot distance, 66% of the plume was still visible and the remainder had been mixed by edge eddies to the point where it was no longer visible. On this basis the observed visible plume was considered equal to σ_z. Plume heights were determined by comparing the observed dust cloud height against a marked reference pole.

The form of the dispersion equation used in this analysis was designed for use in estimating ground level concentrations resulting from emissions from an infinite line source. However, due to the significant backwash of filtered air from the motor, hi-volume samplers can generate suspended particulate if monitors are located too close to the ground. EPA guidelines for location of hi-volume monitors specify a minimum elevation of two meters. The possibility of a significant difference in concentration due to variation in the monitoring height was considered. Samplers were run at elevations of 1, 2, and 3 meters above the surface. Nine such tests were run in order to get some idea as to the plume vertical distribution, and specifically to determine whether or not a sampler at a standard two-meter elevation accurately reflects the source emission concentration.

In Figure 2 the average relative concentration (proportional to 2 meter concentration) was plotted against sampler height. The figure shows that between the two and three meter elevation, the variation in concentration is rather small, while differences between the measured concentration at one and two meters is significant. Suspended particulate concentrations one meter above the surface were approximately 1.4 times larger than the measured concentrations at two meters. Also plotted in Figure 2 is a curve representing calculated variation in relative concentration with height. Concentrations were calculated assuming a uniform σ_z of four meters and averaging concentration contributions from emitters at four heights (0.2 m, 1.2 m, 2.2 m, 3.2 m) observed during field tests. It can be seen that while measured relative concentration variation with height between two and three meters closely approximates calculated variations, the observed variation between one and two meters far exceeds that variation which one would normally expect. For this reason, it was concluded that concentration measurements taken at one meter were unrepresentatively high, possibly due to the backwash mentioned earlier.

Calculation of concentration distribution with height also served to verify the assumption implicit in the emission factor calculation that concentration measurements taken at a height of two meters were reasonably representative of actual ground level concentrations. In the example calculation, ground level concentrations are only 10% higher than concentrations at two meters. This possible 10% variation is well within limits of error encounted for other calculation variables.

Summary And Conclusions

A series of field tests were conducted in the Tucson area in order to determine the most suitable emission rate figures for fugitive dust resulting from vehicular travel over unpaved roads. Hi-volume air samplers were used upwind and downwind from the roadway in question. The difference between these values was considered to be due to the source, and a diffusion model was used to calculate the source strength.

Soil samples were collected from 12 unpaved roads, and the average silt content was found to be 9%. The silt content of adjacent undisturbed desert soils was considerably higher, 23%. Emission rates appear to vary *directly with road silt content. Tests taken the third day* after heavy rains showed no difference in emission rates when compared to days prior to rain.

Five roads were sampled with a total of 46 emission rate measurements covering traffic speeds from 10 to 50 miles per hour. At 30 mph the average emission rate for a road with 10% silt was about 3 lbs/vehicle mile. The emission rates appear to vary exponentially with traffic speed, and the equation which best approximates the experimental data is:

$$E = (\text{silt})\ (c)\ (\text{mph})^2 \qquad (6)$$

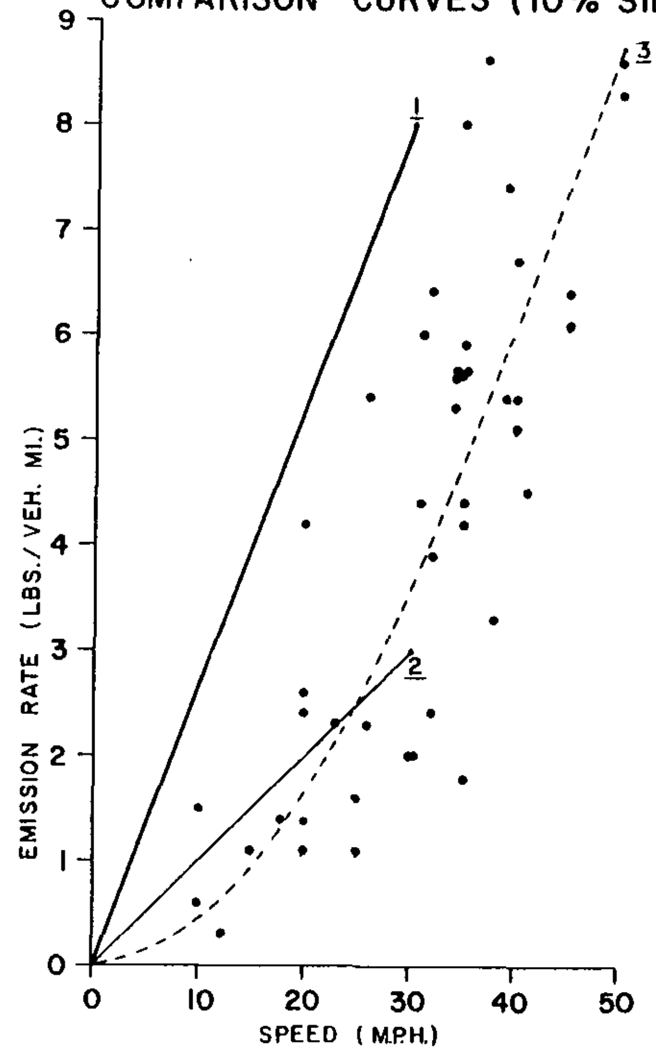
Where: E = Emission rate (lbs/vehicle mile)

silt = Silt content of road expressed as a fraction

c = Empirically derived coefficient = 0.035

mph = Traffic speed in miles per hour

EMISSION RATES vs TRAFFIC SPEED
COMPARISON CURVES (10% SILT)



1 EPA E=(0.81) (SILT %) (M.P.H./30)
2 EPA WITH SMALLER CONSTANT (0.3)
3 E=(.035) (SILT FRACT.) (M.P.H.)²

FIGURE I

VARIATION OF RELATIVE CONCENTRATION WITH HEIGHT

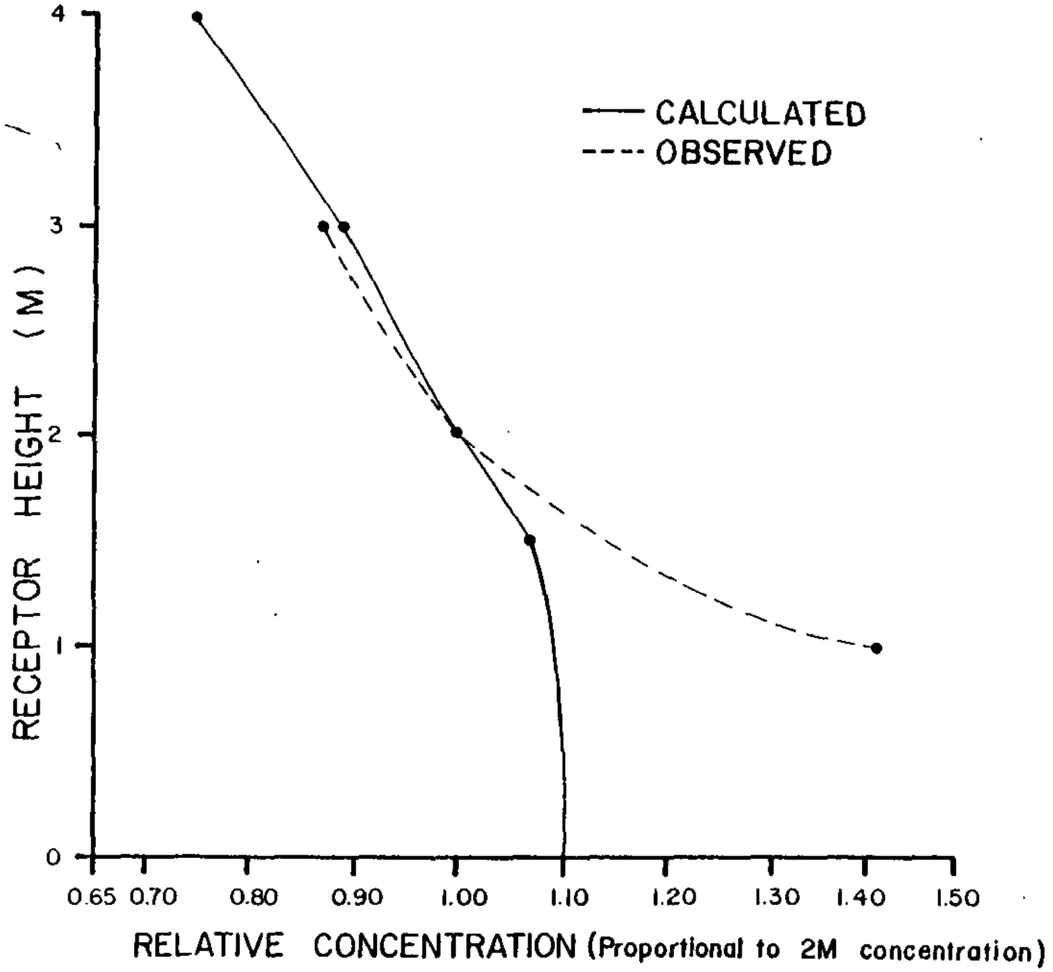


FIGURE 2

References

1. PEDCo Environmental Specialists, Inc., "Investigation of Fugitive Dust - Sources Emission and Control", Final report prepared by EPA under Contract No. 68-02-0044, (May 1973).

2. J.W. Roberts, et al., "Dirty roads = dirty air", APWA Reporter, (11): 10 (1973).

3. J.W. Roberts, et al., "Cost benefits of road dust control in eattle's industrial valley", J. Air Poll. Control Assoc, 25 (9): 948 (1975).

4. C. Cowherd, Jr., "Development of Emission Factors for Fugitive Dust Sources", U.S. EPA Document, EPA-450/3-74/073 (June 1974).

5. U.S. Environmental Protection Agency, Office of Air Programs, "Compilation of Air Pollutant Emission Factor", Publication No. AP-42, (Supplement No. 5, December 1975).

6. D.B. Turner, "Workbook of Atmospheric Dispersion Estimates", Public Health Service Publication No. 999-AP-26 (Revised 1969).

7. R. Dyck and J. Stukel, "Fugitive dust emissions from trucks on unpaved roads", Environ. Sci. Technol., 10 (10): 1046 (1976).

8. J.D. McCain, et al., "Methods of determining particulate mass and size properties: laboratory and field measurements", J. Air Poll. Control Assoc., 24 (12): 1172 (1974).