NILU TR : 6/86
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ISBN 82-7247-727-0

SUMMARY

Results of seven dual tracer experiments (SF_6 and $CBrF_3$) show that the vertical diffusion of exhaust gases increase as a result of increased driving speed of the cars. The experiments were carried out over a flat snow covered plain and with tracer gases emitted from two moving cars. The vertical distribution of tracer were determined at 10, 30 and 70 m from the road using 5-10 m masts. Gaussian distributions were found to fit the vertical profiles of tracer concentrations.

When the atmospheric wind was perpendicular to the road, the vertical dispersion parameter for tracer material (σ_z) was linearly dependent on the scale of the wake in each experiment. The coefficients of linearity varied with the state of the atmospehric surface layer as indicated by wind measurements and stability classification.

The empirical results are applicable only when the scale of turbulence in the atmospheric surface layer are smaller than the scale of the wake. Houses and trees located close to the road will influence with the dispersion of the automobile exhaust.

CONTENTS

THE INFLUENCE OF CAR SPEED ON DISPERSION OF EXHAUST GASES

1 INTRODUCTION

In Norway as in other countries automobile exhaust is an important air pollution problem, particularly for persons living or working closer than 100 m from roads with high traffic loads. Therefore, use of dispersion models to describe the extent of the polluted area adjacent to roads in different regions is important in connection with urban and traffic planning.

The highest pollution loadings occur particularly in the winter when the atmospheric turbulence is small. The following models have been used in Norway to provide information on pollutant concentrations close to roads with high traffic:

- EPA HIWAY-model (Zimmerman and Thompson, 1975)
- Model based on General Motors (GM) Study (Chock, 1977)
- The Nordic model for concentration calculations in street canyons (Larssen, 1984).

The EPA HIWAY-model employs Pasquill-Giffords dispersion parameters for the atmospheric surface layer to calculate pollution concentration close to highways. The importance of vehicle wakes for the dispersion of pollution close to a road is well documented (Chock 1977), based upon tracer experiments and on theoretical evaluation (Eskridge et al. 1979).

The diffusion can be viewed as the result of the interaction between the development of the vehicle wake and the dispersive state of the atmosphere. The development of the vehicle wake is dependent on the vehicle speed and the size and shape of the vehicle. The dispersive state of the atmosphere is dependent on the size and structure of the roughness elements, the terrain, the wind speed and the surface-layer heat balance.

The interaction further depends on the wind direction to the roadway, the wind shear and on the thermal stratification of the atmosphere.

The EPA HIWAY-2 model (Petersen, 1980) includes the results of General Motors tracer experiments and sugestions for improvements formulated in a paper by Rao and Keenan (1980).

In Norway the GM measurements were taken into account in selecting dispersion parameters, but the general applicability under Norwegian conditions (climate and traffic) was questioned.

SF_6 tracer studies were conducted to clarify the variation of car influenced dispersion with meteorological conditions (Grønskei, 1981). The results indicated that the speed of the cars have to be high for the GM-model to be applicable close to small roads during stable atmospheric situations.

To better understand the interaction between the car wakes and the atmospheric surface layer, tracer experiments were carried out with different car velocities. Two cars emitting different tracer components (SF_6 and $CBrF_3$) were driven one after the other with different speed.

The fast moving car (80 km/h) was followed by the slow moving car (40 km/h) along the test section of the road, and the wakes behind the cars did not interfere with each other. The driving procedure was repeated and the contribution of tracer gases after 6-8 traverses was collected in a sampling system.

The samples of the tracer gases were taken downwind of the road using plastic syringes for the two components. The instruments and equipment used for tracer sampling are described by Heggen and Sivertsen (1984).

This emission and sampling procedure were selected in order to minimize the difference in dispersion resulting from variations in the ambient wind and turbulence condition. By changing the driving procedure it was possible to study dispersion effect of parameters describing the wake development i.e. the speed of the cars.

2 TRACER EXPERIMENTS

Seven dual tracer studies were conducted in March and April 1982 by the road Rv-22 in Skedsmo, Norway. The course of the tracer-emitting cars and the sampling stations are shown in Figure 1.

Apart from a 10-15 m deep river canyon and a small forest the test grounds were flat. At the time of the experiment, the area was snow-covered.

The location of tracer samplers attached to three masts are shown. The masts are located 10, 30 and 70 m from the edge of the road. One sampler is located about 1 m from the edge of the road and 1 m above the ground level.

Measurements of wind speed and wind direction were carried out on top of the 10 m mast, 30 m from the edge of the road using a Woelfle wind recorder. Wind speed was further recorded 5 m and 1 m above the ground over the sampling periods by using "Fuess small wind recorders". The temperature 5 m above the ground and 1 m above the ground were determined by using one ventilated thermometer first at 5 m level and then at 1 m level before and after each experiment.

The tracer concentrations were determined as 15 min average values.

<u>Emission procedure</u>:

Two cars were driven along the 648 m road segment emitting tracer gases from tubes attached to the exhaust pipes of the cars. The height of the cars emitting tracer gases was 1.3 m. The emission intensity was recorded by a calibrated gas flow meter. The accuracy of the emission intensity is estimated to be about ± 10% considering control of the flowmeter setting in the cars and the flowmeter calibration curve. To avoid influence of systematic errors in the concentration determination of the two tracer gases, the tracers were emitted alternatively from the car driven with high speed and from the car driven with low speed.

a)

b)

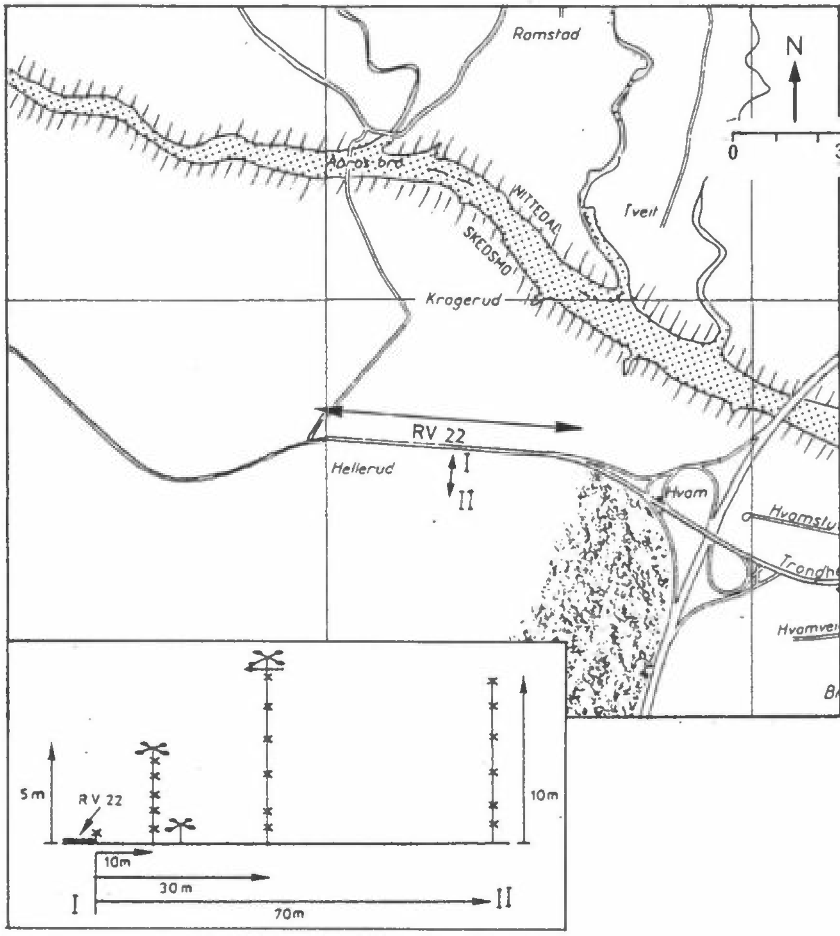


Figure 1. a) A map of the test field
b) A cross section of the sampling network.

The wakes of the emission cars did not interfere with each other. The wake from other cars however could interfere with the line source of emission. Interference between wakes occured:

- when the slow moving car was passed by an other car 1-2 times in each experiment. The car driving with 80 km/hour was not passed by another car.

- in the zone of meeting between cars with opposite driving direction. This occured 0-5 times in each emission traverse.

During the sampling periods 6-8 emission traverses were made over the road segment. The driving time for each car was recorded by a stop watch, and the average driving time was used to determine the driving speed of the emission cars.

3 RESULTS

The tracer concentrations for each experiment, are shown in Appendix 1.

The meteorological conditions (Table 1) and the emission data (Table 2) are shown for each experiment.

Table 1. Date and time of experiments. Meteorological measurements.

No	Date	Time	U_{10}	U_5	U_1	φ_{10}	ΔT	$U_\perp$	Remarks	Stab.
			m/s	m/s	m/s	deg	^0C	m/s		
1	1982-03-29	1135-1150	.8	2.4	1.8	90	+ 0.1	-	Parallel	S
2	1982-03-29	1245-1300	1.1	0.7	0.5	10	-	1.1	Perpend.	N
3	1982-03-31	0955-1010	1.4	0.8	0.8	90	-	-	Parallel	N
4	1982-03-31	1043-1058	0.3	0.9	0.6	260	-	-	Windshift	N
5	1982-04-13	1415-1430	5.6	5.8	4.0	20	- 0.5	5.4	Perpend.	N
6	1982-04-13	1930-1945	1.3	1.8	1.0	30	0-0.2	1.2	Perpend.	S
7	1982-04-19	2050-2105	2.7	2.0	1.2	15	0-0.1	2.7	Perpend.	S

$\left.\begin{array}{l} U_{10} \\ U_5 \\ U_1 \end{array}\right\}$: Wind speed 10 m, 5 m and 1 m above the ground.

φ_{10} : Wind direction 10 m above the ground.

ΔT : Temperature difference between 5 and 1 m. Two numbers refer to measurements before and after the tracer experment.

$U_\perp$: Windspeed perpendicular to the road. The orientation of the road is 95 - 275 degree (see Figure 1).

Remarks: The experiments are classified according to observation of wind direction in relation to orientation of the road. (Parallel, perpendicular or wind shift.)

Stab. : The experiments are classified according to observation of wind and temperature stratification.

S : Stable atmospheric surface layer.

N : Neutral atmospheric surface layer.

Table 2. Emission data.

Testnumber	Q_{SF_6}	V_{SF_6}	Q_{CBrF_3}	V_{CBrF_3}
	10^{-3} ml/ms	km/hour	10^{-3} ml/ms	km/hour
1	1.2	80	33	40
2	2.4	40	16	80
3	12	~5	22	80
4	12	~5	43	40
5	9.4	~5	27	80
6	1.4	80	33	40
7	3.3	40	22	80

Q_{SF_6}] Emission rate of SF_6.
V_{SF_6}] Speed of the car emitting SF_6.

Q_{CBrF_3}] Emission rate of $CBrF_3$.
$CBrF_3$] Speed of the car emitting $CBrF_3$.

The σ_z-values shown in Table 3 were determined by the least squares approximation of the observed vertical concentration profile to a Gaussian distribution

In addition to the σ_z-value, the first moment of the vertical concentration tion distribution was estimated.

$$\overline{z} = \frac{\int_0^\infty czdz}{\int_0^\infty cdz} \qquad \text{(Eq. 1)}$$

In oblique wind situations (parallel), the vertical extent of the tracers was large, and the profile observations in 5-10 m high masts were not adequate for estimating the first moment.

In most cases the least squares fit to a Gaussian curve was used to determine the standard deviation of the observed vertical tracer profile. In some cases, this method gave unreasonable σ_z-values, as when the top of the tracer cloud was not determined by measurements. Rao (1980) suggested to use two single measurements to determine the σ_z-values by equation 2.

Table 3. The standard deviation (σ_z) and the first moment ($\bar{Z}$) for the vertical tracer concentration profiles for each experiment. V is the car speed V ~ 5 km/hour means walking.

Test	Tracer	V	10 m σ_z	10 m $\bar{Z}$	30 m σ_z	30 m $\bar{Z}$	70 m σ_z	70 m $\bar{Z}$
		km/h	m	m	m	m	m	m
1	SF_6	80	4.65	-	(12.48)	-	-	-
	$CBrF_3$	40	4.25	-	12.10	-	-	-
2	SF_6	40	2.95	2.12	4.77	3.37	7.70	-
	$CBrF_3$	80	2.45	2.04	8.91	3.55	9.70	-
3	SF_6	~5	5.35	-	4.59	-	9.41	-
	$CBrF_3$	80	4.05	-	6.21	-	14.54	-
4	SF_6	~5	3.55	-	7.90	-	-	-
	$CBrF_3$	40	4.45	-	6.70	-	-	-
5	SF_6	~5	2.05	1.57	(2.81)	1.82	8.84	5.15
	$CBrF_3$	80	2.25	1.87	4.85	3.59	(4.80)	3.87
6	SF_6	80	2.15	1.77	2.79	2.49	4.05	3.20
	$CBrF_3$	40	1.95	1.68	2.43	2.10	2.97	2.49
7	SF_6	40	1.48	1.79	2.19	2.18	3.57	3.75
	$CBrF_3$	80	2.20	1.88	3.52	2.96	3.99	3.75

$$\sigma_z^2 = \frac{z_2^2 - z_1^2}{2 \ln (C_1/C_2)} \qquad \text{(Eq. 2)}$$

C_1 and C_2 are the measured concentrations at the levels z_1 and z_2 respectively.

To reduce the effect of errors in single measurements the average value of the two lowest and the two highest measurements were used to estimate C_1 and C_2 in equation 2. The σ_z values obtained using individual observations are shown in Appendix 2.

The values calculated using Eq. 2 with average values for C_1 and C_2 are given in parantheses in Table 3, indicating that a different method of calculation is used.

The vertical dispersion of tracer material at different distances was calculated in two different ways (see Table 3).

When the vertical profile exhibits a Gaussian distribution with a maximum concentration at ground level, the following relation should exist between $\bar{z}$ and σ_z:

$$\bar{z} = \sqrt{\frac{2}{\pi}}\,\sigma_z \qquad \text{(Eq. 4)}$$

The average value of $\frac{\bar{z}}{\sigma_z}$ for the numbers given in Table 3 is 0.78 which is a good approximation of $\sqrt{\frac{2}{\pi}}$.

The tabled results suggest that when the driving speed is high, the σ_z-values become large. In oblique windsituation (test 1, 3 and 4) the observed σ_z-values become large and the accuracy is probably poor since the masts are not high enough to cover the profiles. Increasing the driving speed to 80 km/h gives 10-20% higher σ_z-values close to the road. It was a tendency for the difference in σ_z-values for different driving speeds to increase with distance from the road.

For the consideration of uncertainty the following observations are made:

1) Different methods of σ_z-calculation from profile observations give different σ_z-estimates. The standard deviation of the difference between the estimates is 0.4 m (14% of the average σ_z-value). The absolute value of the difference decreases with decreasing σ_z-values.

2) The linear regression between the σ_z and $\bar{z}$ values given in Table 3 yields:

$$\bar{z} = 0.7\ \sigma_z + .44\ (R = 0.91)$$

In a Gaussian distribution, the ratio between the first moment and the standard deviation is 0.8 ($\bar{z}/\sigma_z = 0.8$). Results of the Student T-test show that the present data support this interrelation at the 95 percent significance level.

3) Increased vertical standard deviation with increased driving speed is observed at the 95% significance level according to result of the Student T-test.

Based on these observations it was concluded that the vertical dispersion increased as a result of increased driving speed.

Using the HIWAY-2 model the σ_z-values at different distances from the road were calculated for the experiments 2, 5, 6 and 7. The calculated σ_z-values (σ_c) are compared with the observed values (σ_0) in Figure 2.

This figure shows that for test 6 and 7 the calculated values represent overestimates. For test 2 and 5 the correspondence between calculated and observed values is acceptable. For each calculated value in Figure 2, two observed values are shown, one for low car speed and one for high car speed. In 10 out of 12 cases depicted, higher driving speed yields larger σ_z values in comparison to the lower driving speed results.

The concentration measurements 1 m from the edge of the road and 1 m above the ground were used to estimate the σ_z-values close to the road. The corresponding values were calculated using HIWAY-2 and the results of calculations are shown in Table 4.

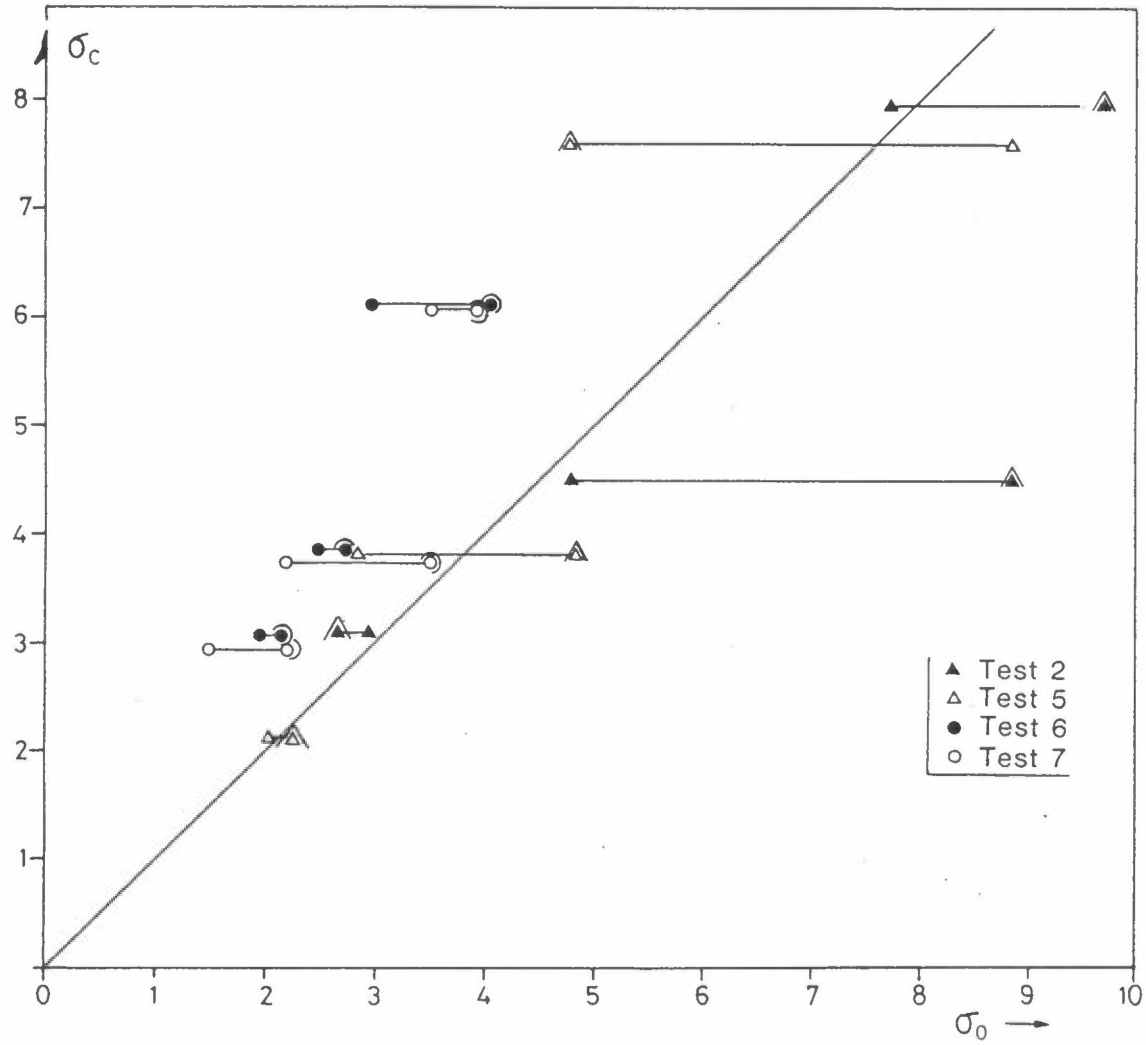


Figure 2: Scatter diagram between observed (σ_o) and calculated σ_z values (σ_c). The calculated values refer to the HIWAY-2 model. Two observed values connected by a horizontal line represent two values for different driving speeds. The marked points represent the σ_o-value for the car with high driving speed.

In test number 2, 6 and 7, characterized by wind perpendicular to the road, the calculated σ_z-values (HIWAY-2) apears to be larger than the observed values. The reason for the discrepency is probably that HIWAY-2 is developed for the fast running traffic at a highway with two lanes for each direction. Rv-22 in Norway is smaller and the adjacent ground is flat and snow covered.

Table 4. σ_z-estimates at the edge of the road based on concentration observation and emission data. The values are compared with the corresponding σ_z-values calculated by HIWAY-2.

Forsøk	Co	Q	u (1m)	σ_0	V_W	σ_C
	ppt	10^{-3} ml/m.s	m/s	m		m
1 $CBrF_3$	26853	33	1.8	0.5	40	
1 SF_6	755	1.2	1.8	0.7	80	
2 $CBrF_3$	7403	16	0.8	2.2	80	2.9
2 SF_6	1355	2.4	0.8	1.8	40	
3 $CBrF_3$	13290	22	~0.5	2.6	80	
3 SF_6	7100	12	~0.5	2.7	~5	
4 $CBrF_3$	7396	43		-	40	
4 SF_6	3097	12		-	~5	
5 $CBrF_3$	2432	27	4.0	2.2	80	1.8
5 SF_6	2405	9.4	4.0	0.8	~5	
6 $CBrF_3$	17550	33	1.0	1.5	40	2.9
6 SF_6	556	1.4	1.0	2.0	80	
7 $CBrF_3$	7460	22	1.2	2.0	80	2.8
7 SF_6	1364	3.3	1.2	1.6	40	

$$\sigma_0 = \frac{Q}{C_0 \cdot u} \sqrt{\frac{2}{\pi}}$$

Q : Emission of tracer gases on the road.

C_0 : Tracer concentration 1 m above ground level by the edge of the road.

U (1m) : Wind speed at the height of 1 m.

V_W : Speed of the car.

σ_C : The standard deviation calculated by using the HIWAY-2 model.

4 DISCUSSION OF RESULTS

4.1 ESTIMATES OF EMISSIONS

The simultaneous measurements of wind and concentration profiles were used to estimate the flux of tracer gases perpendicular to the road at different distances. Equation 3 was applied to estimate the fluxes

$$F = \int_0^H ucdz \approx \sum_{k=1}^{5} u_k C_k \Delta z_k \qquad \text{(Eq. 3)}$$

Interpolations were made between observed C-values and U-values.

The flux estimates are compared with the emission estimates in Table 5. In oblique wind situations (test No. 1, 3 and 4) the flux estimates may differ considerably from the emission estimates.

Considering experiments with wind perpendicular to the road, high discrepancies between flux estimates and emission intensities are found 30 m and 70 m from the road in test number 5. These σ-values should be used with caution.

For test 2 an excellent agreement between flux estimates and emission intensity is found for SF_6. For $CBrF_3$ average value of fluxes overestimates the emission intensity by 8%. At 30 m the high flux estimate indicate that the σ_z-value for the fast running car may be overestimated.

For test 6 average value of fluxes overestimates the emission intensity by 2% for SF_6 by 14% for $CBrF_3$.

For test 7 average value of fluxes overestimates the emission intensity by 41% for SF_6 by 3% $CBrF_3$. The fluctuation in fluxes indicates that the σ_z-value for the slow moving car may be overestimated and that the σ_z-value for the fast car may be underestimated.

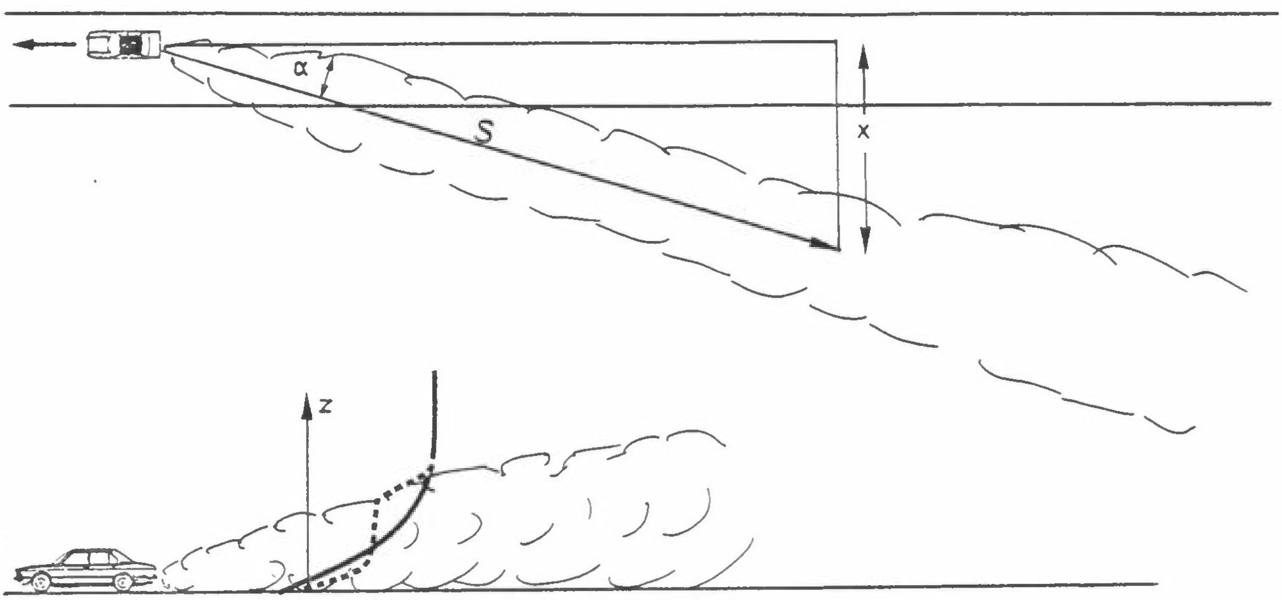
When the flux estimates are consistently different from the emission intensity, errors may be found in the emission system or in the measurements of wind (speed and direction). The estimation of σ_z-values from profile measurements is probably more accurate than indicated from the emission/flux relationships. The determination of the σ_z-values is not dependent on the absolute tracer concentration value. In that way correct σ_z-values may be obtained regardless of errors in the emission system or in the measurements of wind.

Table 5. Line source emission intensity and fluxes of tracer gases calculated for each experiment. Unit = 10^{-3} ml/m.s.

Experiment	Emission	Flux		
		10 m	30 m	70 m
1 SF_6	1.2	1.8	2.0	(1.8)
$CBrF_3$	33	52	47	(36)
2 SF_6	2.4	2.5	2.5	2.5
$CBrF_3$	16	14.5	20	18
3 SF_6	12	-	11	5.5
$CBrF_3$	22	26	23	27
4 SF_6	12	3.2	7.0	2.4
$CBrF_3$	43	19	21	-
5 SF_6	9.4	8.0	4.9	3.4
$CBrF_3$	27	29	38	17.7
6 SF_6	1.4	1.7	1.6	1.3
$CBrF_3$	33	37	37	39
7 SF_6	3.3	4.8	3.7	5.5
$CBrF_3$	22	21	25	17.9

4.2 PARAMETERS DESCRIBING THE WAKE

The turbulent wake behind the car often contain two vortices with opposite vorticity. This wake interact with the background atmosphere to produce the observed dispersion of tracer gases. The wakes containing the tracer and the exhaust gases are transported with the wind velocity. A description of this situation is shown in Figure 3.



$$\text{Sin } \alpha = \frac{x}{s} \approx \frac{U_\perp}{V}$$

$$s = \frac{V}{U_\perp} \cdot x$$

s : The distance from the car to an observation point.
X : Distance from the road to an observation point.
$U_\perp$: Wind speed perpindicular to the road.
V : Car speed along the road.

Figure 3: The wake behind the car is moved perpendicular to the road by the wind.

The dependence of σ_z-values on the car speed and the development of the wake has been decribed by Eskridge and Hunt (1979).

According to this theory the scale of the wake (l) increases with distance behind the car.

$$l = \lambda \, Ah \left[\frac{s}{h} \right]^{0.25} \qquad \text{(Eq. 5)}$$

s : distance behind the car
h : height of the car
λ and A: factors of proportionality

According to Equation 5 and the simple geometrical relationships shown in Figure 3 the following parameter, can be shown to be related to the scale of the wake at different distances from the road

$$l' = \left(\frac{V}{U}\right)^{0.25} \left[\left(\frac{x}{h}\right)^{0.25} - 1\right] \qquad \text{(Eq. 6)}$$

when x = h then l' = 0.

For each experiment with wind perpendicular to the road the observed σ_z-values are plotted against l' in Figure 4.

For each of the experiments (test Nos 2, 5, 6 and 7) the σ_z-values indicate a linear dependence on the scale of the wake.

The following equation applies for each experiment.

$$\sigma_z = al' + b \qquad \text{(Eq. 7)}$$

Lines are drawn for the different tests in Figure 4. It seems reasonable that the value of b is less than 1 m considering a wake behind a 1.3 m high car. The coefficient of linearity (a) is larger in test 2 and 5 compared to test 6 and 7. The variation in the coefficient (a) remains to be explained by the interaction between the atmospheric surface layer and the finite disturbances behind the cars. According to the meteorological measurements shown in Table 1, the surface layer is classified as neutral in test 2 and

5, stable in test 6 and 7. The coefficient (a) is expected to be proportional to the height of the cars (h) and to decrease with increasing thermal stability. In the atmospheric surface layer the wind shear increases when the thermal stability increases. Increased wind shear is expected to increase the dispersion effect of the wake as more kinetic energy become available for the generation of turbulence when the air is mixed by the wake behind the cars.

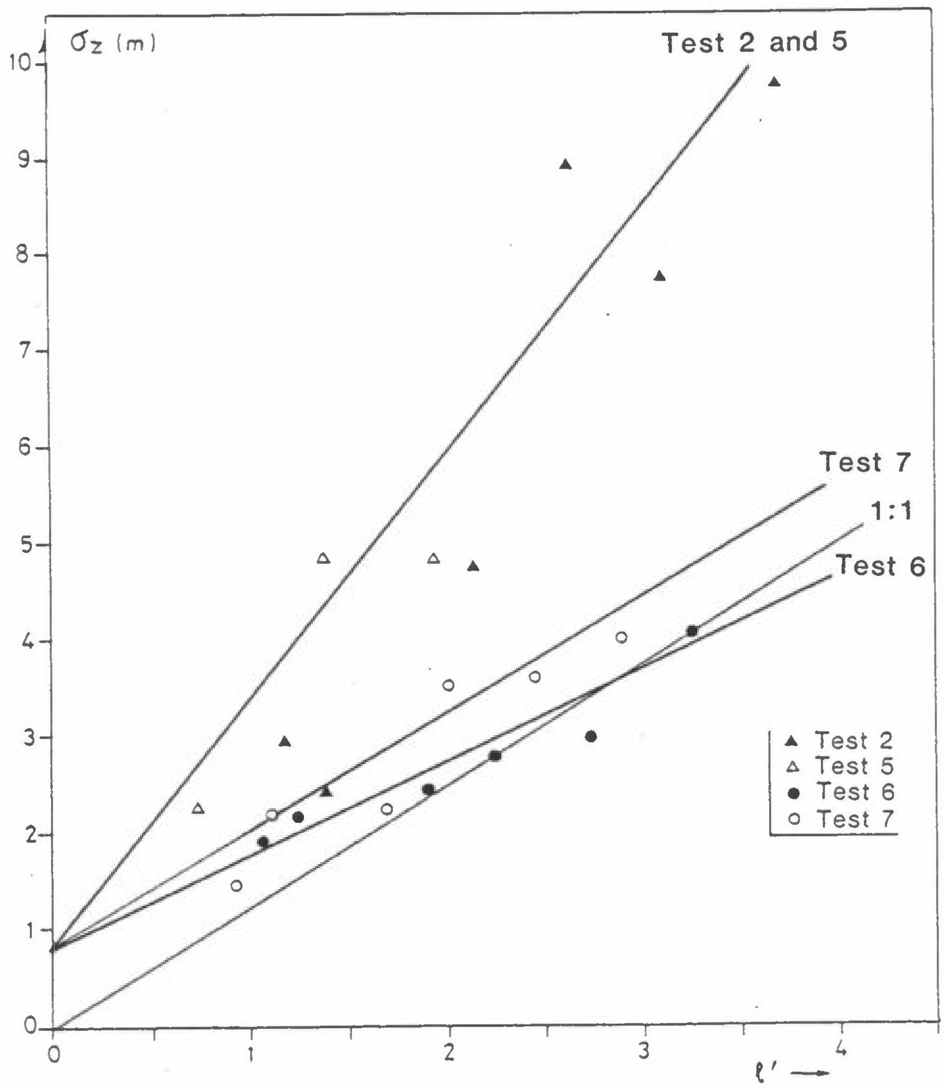


Figure 4: The dependence of standard deviation of the vertical concentration profile on the scale of the car wake.

A linear relationship between l' and σ_z seems reasonable close to the road, when turbulent intensity behind the car is larger than the turbulent intensity in the atmosphere. At larger distances the atmospheric turbulence will determine the diffusion.

Assuming the diffusion effect of the car generated turbulence (σ_w) and of the atmospheric turbulence (σ_a) to be additive the following approximation is proposed.

$$\sigma_z^2 = \sigma_a^2 + \sigma_w^2 \qquad \text{(Eq. 8)}$$

σ_a : diffusion by the atmospheric turbulence, to be selected for the area under consideration.

$$\sigma_w = \frac{\pi}{2} \cdot h \left(1 + 4C \left(\frac{V}{U}\right)^{0.5} \left(\left(\frac{x}{h}\right)^{0.5} - 1\right)\right)^{0.5} \qquad \text{(Eq. 9)}$$

Following Eskridge et al. (1979):

$C = 0.046$

The background for the equations 8 and 9 is discussed by Grønskei (1982). Empirical results (Eg. 7) and simplified theoretical considerations (Eg. 8 and 9) indicate that the scale of car wakes as defined by Eskridge and Hunt (1979) may be used to improve description of dispersion of exhaust gases close to roads.

4.3 APPLICATION OF TRACER DATA RESULTS

Data for turbulence intensity and scale of the turbulence in the wake may be used to describe possible interaction between the surface layer of the ambient atmosphere and the wakes behind the cars. The observed dispersion of the pollution emitted in the wakes is the sum result of this interaction. With the notation of Eskridge et al. (1979), we refer to Figure 5 for classification purposes.

Turbulence intensity in the wake: $i_{zw} = (\overline{W'^2})^{0.5}/U$.

Scale of the wake: l_w.

Turbulence intensity in the atmospheric surface layer: $i_{za} = a\,\frac{U_*}{U}$

Scale of the atmospheric turbulence: l_a.

$(\overline{W'^2})^{0.5}$: root mean square of the vertical velocity fluctuations

U : horizontal wind speed

a : factor of proportionality

U_* : friction velocity of the atmospheric surface layer.

- When the scale of the wake is larger than the scale of atmospheric turbulence ($l_w/l_a>1$) atmospheric gradients in the wind and temperature may be influenced by wakes. The gradients should be considered for the further development and for the dispersion of pollution emitted in the wake. The region is indicated by the two hatched areas in the right part of figure 5. The area in the upper part of the figure represent the conditions close to the road when the turbulence intensity caused by the vehicles dominates over the intensity in the atmospheric surface layer. In an inversion situation wake mixing of thermally stratified air cause buoyant forces that may increase vertical mixing. On the other hand thermal stratification outside the wake restricts vertical movements. Wake parameters may be important for dispersion as a result of the development of two finite vorticies introduced in the atmospheric surface layer.

- When the scale of the wake is approximately equal to the scale of atmospheric turbulence ($l_w/l_a \sim 1$) atmospheric gradients are probably not important for the development of the wake. This situation is described by the theory of Eskridge et al. (1979). For these cases atmospheric and wake turbulence determine the diffusion. Close to the road the increased turbulence intensity will increase dispersion. At some distance from the road the atmospheric dispersion parameters may be used to describe the growth of the pollution cloud. Moving along the horizontal axis in figure 5 this region is indicated by an open area between the hatched regions.

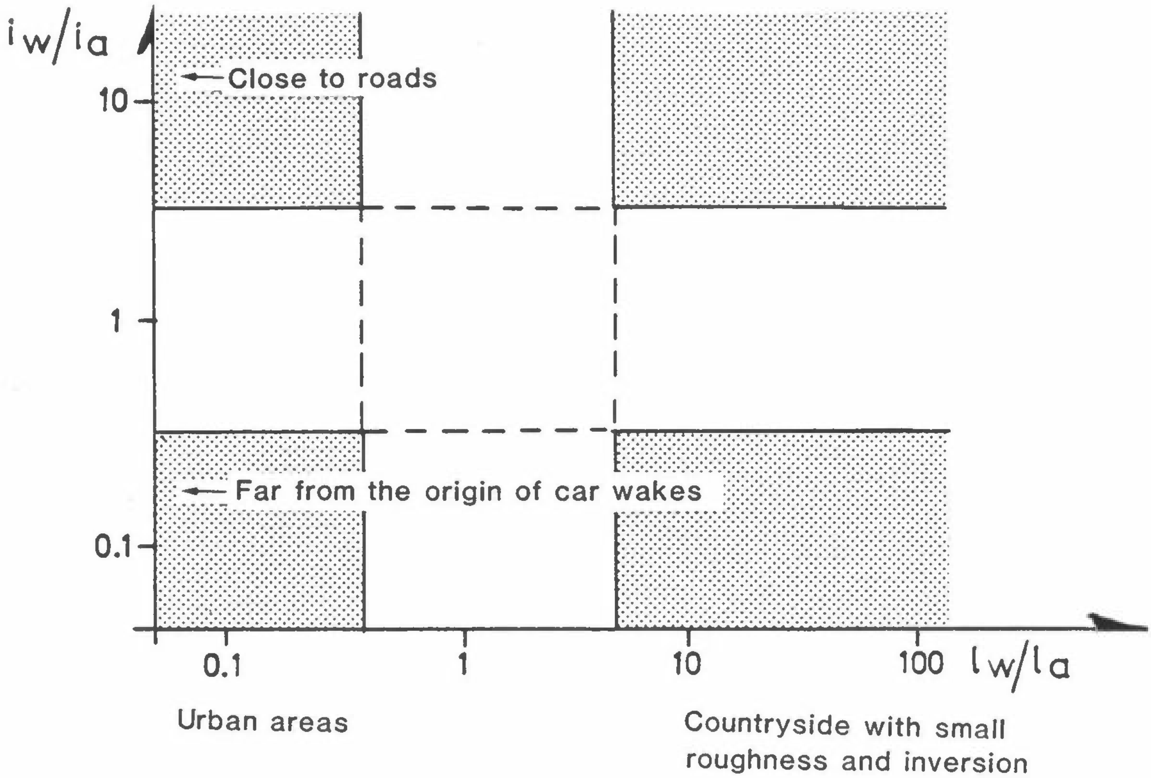


Figure 5: Classification scheme of results from tracer experiments and of the applicability of line source dispersion models.

- Close to the ground, wakes from other roughness elements (houses and trees) may interfere with the dispersion. Car wake parameters may not be important for the dispersion parameters except in the immediate neighbourhood of the cars when the turbulence in the wake is larger than in the atmospheric surface layer. The region is indicated by the two hatched areas to the left in figure 5. Far from the car exhaust emission the pollution concentration will have a stochastic variability that is not described by wake parameters. In these situations the car wake development is not restricting the dispersion process.

The dual-tracer experiments are carried out in situations when $l_w \geq l_a$ over a flat snow covered area. Parameters describing the car wake did also show up in the description of the dispersion. In the analyses with winds perpendicular to the road, HIWAY-2 overestimated the dispersion for the stable atmospheric cases. For the cases with neutral stability, HIWAY-2 seemed to perform adequately.

Tracer experiments in the urban area of Sarpsborg resulted in six σ_z values between 26 and 73 m (average value: 48 m) at the distance of 150 m from a road (Grønskei, 1984). HIWAY-2 underestimated the vertical diffusion in these experiments, possibly resulting from not adequately accounting for the effects of larger roughness elements (houses and trees) in the residential area. More empirical data are needed on the diffusion of car traffic emissions in urban areas, particularly at the distances of 10-100 m from the road. Parameters characterizing the wakes behind the houses and the trees are expected to be important for the description of vertical diffusion.

5 CONCLUSIONS

Results of two component tracer experiments show increased vertical dispersion as a result of increased driving speed of the cars (from 40 to 80 km/h). The car speed influences the development of the wake, which in turn affects the diffusion. The faster the car speed the faster the growth of the wake. The experiments were carried out over a flat snowcovered plain. A Gaussian distribution was found to fit the vertical distribution of tracer concentration. The standard deviation of the vertical tracer distribution may reveal a linear dependance on a parameter describing the vertical scale of the wake.

When the wind shear is small and car speed is small the effect of the car wake is minimized over a flat surface in a stable surface layer. The tracer experiments indicate that in these cases HIWAY-2 model underestimates the pollution concentration by the roadway.

The empirical result may not be reproducible when the vertical scale of atmospheric turbulence is larger than the scale of the wake. When houses and trees are present close to the road, the wake of the cars are not believed to be important exept in the immediate neighbourhood of the road. HIWAY-2 may overestimate pollution concentration downwind of the street canyon since the wake effects of the buildings are not taken into account in the dispersion parameters.

ACKNOWLEDGEMENTS

The author gratefully acknowlege the useful comments from John Irwin during the preparation of this paper.

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APPENDIX 1

Data on tracer emission and measurements of tracer concentration.

X_s : Horizontal distance from the road in meters.

Z : Height above the ground in meters.

SF_6 : 15 min. average concentration of sulphurhexa-fluoride (SF_6) in ppt.

$CBrF_3$: 15 min. average concentration of carbonbromtri-fluoride ($CBrF_3$) in ppt.

TEST NUMBER: 1 DATE: 20.03.82 TIME: 1135-1150

Emission data: SF_6 : 235 ml/min at 80 km/h $CBrF_3$: 3250 ml/min at 40 km/h
For SF_6 and $CBrF_3$: 6 traverses.

X_s (m):

1			10			30			70		
Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$
1	755	26853	0	223	6465	1	108	3096	1	81	1600
2	425	19514	1	268	7684	2	112	2773	2	78	1597
			2	245	6962	4	96	2228	-		
			3	-	-	6			6	80	1630
			4	99	3095	8			8	83	1613
			5	180	4572	10	95	2003	10	76	1639

TEST NUMBER: 2 DATE: 29.03.82 TIME: 1245-1300

Emission data: SF_6 : 235 ml/min at 40 km/h $CBrF_3$: 3250 ml/min at 80 km/h
For SF_6 and $CBrF_3$: 6 traverses.

X_s (m):

1			10			30			70		
Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$
1	1355	7403	0	520	3754	1	368	2659	1	212	1515
2	-	-	1	637	3393	2	-	-	2	199	1467
			2	460	2870				-	-	-
			3	337	2174	4	160	1596	6	-	-
			4	245	1213	7	109	916	8	139	1008
			5	186	590	9	73	627	10	83	909

TEST NUMBER: 3 DATE: 31.03.82 TIME: 0955-1010

Emission data: SF_6: 235 ml/min at 5 km/h $CBrF_3$: 3250 ml/min at 80 km/h
For SF_6 : 4 traverses. For $CBrF_3$: 8 traverses.

X_s (m):

1			10			30			70		
Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$
1	7100	13290	1	6930	7943	1	3771	4578	1	1017	4310
2		19514	2	5460	8750	2.5	3132	4575	2	853	3677
			3	6755	7738	4.5	2316	3440	-		
			4	5810	5765	7	1246	2363	4.5	564	3978
			5	4135	4259	9	544	1793	7	684	3759
									9.5	536	3260

Concentration in the atmosphere before emission: 12 ppt SF_6; 0 ppt $CBrF_3$.

TEST NUMBER: 4 DATE: 31.03.82 TIME: 1043-1058

Emission data: SF_6: 235 ml/min at 5 km/h $CBrF_3$: 3250 ml/min at 40 km/h
For SF_6 : 4 traverses. For $CBrF_3$ 8 traverses.

X_s (m):

1			10			30			70		
Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$
1	3097	7396	0	1841	6159	1	1047	3212	1	273	1220
2			1	809	6305	2	1043	3370	2	314	301
			2	698	5731	4	-	-	4.5	308	0
			3	819	5649	6	820	2596	6	-	-
			4	681	4947	8	681	1883	7	292	0
			5	1436	3134	10	470	1049	9.5	311	0

TEST NUMBER: 5 DATE: 13.04.82 TIME: 1415-1430

Emission data: SF_6: 2350 ml/min at 5 km/h $CBrF_3$: 4100 ml/min at 80 km/h

For SF_6 : 3 traverses. For $CBrF_3$: 8 traverses.

X_s (m):

1			10			30			70		
Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$
1	2405	2432	0	412	2747	1	455	1881	1	72	1145
			1	987	2894	2	444	1400	2	187	898
			2	588	2134	4	30	913	4.5	140	657
			3	477	1545	6.5	16	888	6.5	123	306
			4	36	841				8		
			5	5	178	9.5	2	215	9.5	73	229

Concentration in the atmosphere before emission: 4 ppt SF_6; 173 ppt $CBrF_3$.

TEST NUMBER: 6 DATE: 13.04.82 TIME: 1930-1945

Emission data: SF_6: 285 ml/min at 80 km/h $CBrF_3$: 3250 ml/min at 40 km/h

For SF_6 and $CBrF_3$: 6 traverses.

X_s (m):

1			10			30			70		
Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$
0	388	11068									
1	556	17550	0	353	10664	1	324	9062	1	210	7826
2	388	11068	1	471	9584	2	239	5704	2	145	5515
			2	392	4203	4.5	105	2336	4.5	93	2575
			3	254	1259	6.5	36	190	7	48	904
			4	72	282	8			8		
			5	6	8998	9	10	126	9	22	126

Concentration in the atmosphere before emission: 3 ppt SF_6; 44 ppt $CBrF_3$.

TEST NUMBER: 7 DATE: 19.04.82 TIME: 2050-2105

Emission data: SF_6: 285 ml/min at 40 km/h $CBrF_3$: 3250 ml/min at 80 km/h
For SF_6 : 7 traverses. For $CBrF_3$: 8 traverses.

X_s (m):

1			10			30			70		
Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$	Z	SF_6	$CBrF_3$
0	829	5370	0	1156	5167	1	679	3520	1	468	1741
1	1364	7460	1	1065	4422	2.5	539	2267	2	-	-
			2	892	3539	4.5	83	2029	4.5	369	979
			3	-	-	7	37	421	7	215	662
			4	301	1646	9.5	12	197	9.5	79	411
			5	8	182						

Concentration in the atmosphere before emission: 4 ppt SF_6; 159 ppt $CBrF_3$.

APPENDIX 2

Calculation of the standard deviation
of a vertical Gaussian distribution

The following formula was used (ref. S. Trivikrama and M.T. Keenan, (1980):

$$\sigma_z^2 = \frac{Z_2^2 - Z_1^2}{2 \ln C_1/C_2}$$

σ_z : Standard diviation of a vertical Gaussion distribution.

Z_2 and Z_1 : Height above the ground of concentration measurements.

C_1 and C_2 : The concentration measured at the height Z_1 and Z_2 respectively.

Test	x	z_1	z_2^2	z_2	z_2^2	$z_2^2 - z_1^2$	C_1	C_2	$\frac{C_1}{C_2}$	$\ln\frac{C_1}{C_2}$	σ_z^2	σ_z	V_v	C_1	C_2	$\frac{C_1}{C_2}$	$\ln\frac{C_1}{C_2}$	σ_z^2	σ_z	V_v
							Based on $CBrF_3$ concentrations							Based on SF_6-concentrations						
	x	m	m^2	m	m^2	m^2	ppt	ppt			m^2	m	km/h	ppt	ppt			m^2	m	km/h
	10	1.5	2.25	4.5	20.25	18.00	7323	3833	1.91	0.65	13.85	3.72		256	139	1.84	0.61	14.75	3.84	
1	30	1.5	2.25	7.0	49	46.75	2934	2115	1.39	0.33	70.83	8.42	40	110	95	1.16	0.15	155.83	12.48	80
	70	1.5	2.25	9.0	81	78.75	1598	1626	1.00	0	-	-		79	79	1	0	-	-	
	10	1.5	2.25	4.5	20.25	18.00	3131	901	3.48	1.25	7.20	2.68		548	215	2.55	0.94	9.57	3.09	
2	30	2.5	6.25	8.0	64	57.75	2127	771	2.76	1.01	28.59	5.35	80	264	91	2.90	1.07	26.99	5.19	40
	70	1.5	2.25	9.0	81	78.75	1491	958	1.56	0.44	89.49	9.46		205	111	1.85	0.61	64.55	8.03	
	10	1.5	2.25	4.5	20.25	18.00	8346	5012	1.67	0.51	17.65	4.20		6195	4973	1.25	0.22	41:0	6.4	
3	30	1.75	3.06	8	64	60.94	4570	2078	2.20	0.79	38.57	6.21	80	3451	895	3.50	1.25	24.38	4.94	Walking
	70	1.5	2.25	8.25	68.06	65.81	3993	3509	1.14	0.13	253.12	15.91		934	610	1.53	0.43	76.52	8.75	
	10	1.5	2.25	4.5	20.25	18.00	2515	509	4.94	1.60	5.63	2.37		787	20	39.35	3.67	2.45	1.57	
5	30	1.5	2.25	8	64	61.75	1640	551	2.98	1.09	28.33	5.32	80	449	9	49.89	3.91	7.90	2.81	Walking
	70	1.5	2.25	8	64	61.75	1021	267	3.82	1.34	23.04	4.80		129	98	1.32	0.27	114.36	10.69	
	10	1.5	2.25	4.5	20.25	18.00	10124	768	13.15	2.58	3.49	1.87		431	39	11.05	2.40	3.75	1.94	
6	30	1.5	2.25	7.75	60.06	57.81	7383	158	46.73	3.84	7.53	2.74	40	281	23	12.22	2.50	11.56	3.40	80
	70	1.5	2.25	8	64	61.75	6670	515	12.95	2.56	12.06	3.47		177	35	5.06	1.62	19.06	4.37	
	10	1.5	2.25	4.5	20.25	18.00	3980	914	5.25	1.66	5.42	2.33		978	154	7.21	1.98	4.55	2.13	
7	30	1.75	3.06	8.25	68.06	65.00	2893	309	9.36	2.24	14.51	3.81	80	609	24	25.38	3.23	10.06	3.17	40
	70	2.75	7.56	8.25	68.06	60.50	1360	536	2.54	0.93	32.53	5.70		418	147	2.84	1.05	28.81	5.37	

NORSK INSTITUTT FOR LUFTFORSKNING (NILU)
NORWEGIAN INSTITUTE FOR AIR RESEARCH

POSTBOKS 130, 2001 LILLESTRØM (ELVEGT. 52), NORGE

RAPPORTTYPE Teknisk rapport	RAPPORTNR. TR 6/86	ISBN-82-7247-727-0	
DATO July 1986	ANSV. SIGN. J. Schjoldager	ANT. SIDER 38	PRIS Kr. 30,00
TITTEL The influence of car speed on dispersion of exhaust gases.		PROSJEKTLEDER K. E. Grønskei	
		NILU PROSJEKT NR. E-8404	
FORFATTER(E) K. E. Grønskei		TILGJENGELIGHET* A	
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OPPDRAGSGIVER (NAVN OG ADRESSE) Norsk institutt for luftforskning P.O.Box 130 2001 LILLESTRØM			
3 STIKKORD (à maks. 20 anslag) Sporstofforsøk	Spredning	Bilavgasser	

REFERAT Spredning av bilavgasser ved en åpen vei er undersøkt i syv sporstofforsøk med utslipp av SF_6 og $CBrF_3$. Utslippet ble foretatt fra to biler som kjørte med forskjellig hastighet. Spredningen ved veien økte med økende hastighet.

TITLE
The influence of car speed on dispersion of exhaust gases

ABSTRACT Dispersion of exhaust gases by an open road is mapped in seven tracer experiments. Two cars emitting SF_6 and $CBrF_3$ were driven with different speed emitting one tracer component each. The dispersion by the road increased with increasing driving speed.

*Kategorier:	Åpen - kan bestilles fra NILU	A
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