PM SIZE MEASURMENT TO SIMULATE THE ATMOSPHERIC DILUTION

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ABSTRACT

The measuring method of vehicular particulate matter (PM) size distribution to simulate the atmospheric dilution process was studied. PM size distribution was measured with a scanning mobility particle sizer (SMPS). To simulate the atmospheric dilution process with a chassis dynamometer test, a chasing experiment was done in order to obtain reference data. A light duty diesel truck was selected as a basic test vehicle. Three sizes of prototype partial flow diluters (PPFD) were made to reproduce the PM size in the atmosphere. The PM sizes of the chasing experiment and the PPFD experiment were roughly agreed. Differences in the data obtained from a full flow dilution tunnel and the chasing experiments were investigated. The length of the transfer tube greatly affected the smaller side of the PM number concentration.

INTRODUCTION

Understanding the physical and chemical characteristics of particles emitted from vehicles is important from the standpoint of human health. Nanoparticles have been observed on and near roadsides in the past few decades (1,6). The size distribution of particulate matter (PM) is known to be greatly affected by the sampling conditions (2-5) and the use of facilities, such as full dilution tunnel systems, to measure the PM weight is not feasible because such facilities cannot reproduce the real PM size distributions in the atmosphere. Chasing experiments are one way to investigate the on-road PM size distribution (6-8). Wind tunnel experiments are a useful way to investigate PM size in the atmosphere. In this study, we attempted to simulate the atmospheric dilution process with a chassis dynamometer test. For this purpose, we used chasing experiments with a track on a test course and chassis dynamometer tests with a simple frame wind tunnel and prototype partial flow diluters built in a room. PM size distributions were measured with a scanning mobility particle sizer (SMPS).

EXPERIMENTAL

The vehicle used throughout these experiment was a 1998 diesel truck with an engine displacement of 4.6L, a maximum power of 96 kW at 3000 rpm, a maximum torque of 333 Nm at 1600 rpm, direct injection, a compression ratio of 19.2:1, a gross vehicle weight of 4535 kg (tested weight 3540 kg), and a mileage of 32600 km. JIS No2 diesel fuel having a sulfur content of 390 ppm was used in the experiments. A Scanning Mobility Particle Sizer (SMPS) was used for PM size measurement. SMPS consisted of DMA: 3081 and CPC: 3025. The up scanning speed was 60 sec and the down scanning speed was 30 sec. The scanning range was 10 to 400 nm. NOx was measured to determine the dilution ratio. A Photo Aerosol Sensor (PAS) was also used to monitor the carbonaceous PM concentration. Chasing Experiments were conducted at JARI's test track. PM sizes were measured along the 1.5-km straight courses only in order to keep the wind effect constant. The NOx concentration was measured in order to determine the dilution ratio (DR). Tailpipe NOx concentrations were measured on the chassis dynamometer. Driving the chasing vehicle alone at certain speeds made background measurements. The tested speeds were 20, 50 and 80 km/h at steady state conditions. The chasing distances were 10 m and 50 m behind the test vehicle. Ten scans of data were measured for each set of conditions and were averaged. The height of the sampling probe was 60 cm above the ground. A simple frame wind tunnel (3.5 m wide x 3.5 m high) was built in the laboratory to investigate the details of the dilution processes of PM . A cooling fan was used for the blower. Prototype partial flow diluters (PPFDs) with 10, 50 and 100 cm diameters were built to simulate the dilution process of tail pipe emissions. Sampling points were 1, 2, and 5 m behind the tail pipe.

RESULTS AND DISCUSSION

The Chasing experiments were done October 9th 2001. The atmospheric temperature was 20.5+/-1.5°C, the relative humidity was 57.7+/-7.6%, and the atmospheric pressure was 1011hPa. The concentration of the exhaust plume was not uniform. In a few seconds, the exhausted PM is diluted several thousand times. The behavior of fine particles and gaseous NOx were almost same, indicating that the values calculated from the NOx concentration are reasonable. The PM size distributions measured by the chasing experiment and the conventional full flow dilution tunnel systems are compared. The PM size distribution obtained with the chasing experiment was corrected by subtracting the background PM size distribution. For the large sized particles, the concentrations measured by the full dilution tunnel and the two chasing experiments agreed relatively well with each other for each of the three speeds. However, for the smaller sized particles, the concentrations were quite different. This indicates that the conventional dilution tunnel system will require some modifications in order for it to reproduce the PM size in the atmosphere. A simple frame wind tunnel was built to reproduce the PM size in the atmosphere. The dilution air was controlled at 25°C and 50% relative humidity. Mixing of the exhaust gas was complete at a distance 10 m behind the tailpipe. The median particle diameter shifted toward a smaller size with increasing distance behind the tailpipe. The PM size distribution measured with the PPFD agreed well with that measured with chasing experiments for each condition. This suggested that the size distribution measured with the full flow dilution tunnel was different. We then attempted to determine why it was different from the size distribution obtained with the chase experiment. To evaluate the effect of coagulation, we used transfer tubes of different lengths in the PPDF. The transfer tube was heated to the temperature of tail pipe exhaust to reduce thermophoretic depositions on the inner wall. As the length of the transfer tube increased, the concentration of smaller sized particles decreased. PM size distribution became closer to the one measured by the full dilution tunnel. At 150°C, the results obtained at 20 and 80 km/h were the same as those observed at 50 km/h .

CONCLUSIONS

The PM size distributions of the exhaust of a light duty diesel vehicle were investigated under different conditions in order to develop a method for reproducing atmospheric dilution processes. First, a chasing experiment was done to obtain reference data for the test vehicle. There were large variations in the PM size distribution, but by averaging 10 scans for each condition, useful PM size distributions could be obtained. The dilution ratios of the particulates rose to a few thousand in the first few seconds after the exhaust was emitted from the tailpipe. The PM size distributions measured with the simple frame wind tunnel and the PPFD were almost the same as the size distribution measured with the chase experiment. A key factor affecting the PM size distribution with a conventional full dilution tunnel is residence time of undiluted exhaust. Further research is needed to determine methods for reproducing the PM size in the atmosphere with many kinds of vehicles and under different conditions.

REFERENCES

1:K.T.Whitby et al. , Characterization of California aerosols-I. Size distributions of freeway aerosol,1975, Atmospheric Environment, Vol 9, pp 463-482 , 2:Ji Ping Shi et al, Investigation of Ultarafine Particle Formation during diesel exhaust dilution, Environ. Sci. Technol. 1999, 33, 3730-3736 , 3:Tristan Davenne , Formation and Groth of Nanoparticles as a result of the Ambient dilution process, ETH conference on Nanoparticlle Measurement 7th August 2001, 4: Khalek,Imad A. et al, Nanoparticle Groth During Dilution and Cooling of Diesel Exhaust: Experimental Investigation and Theoretical Assessment, SAE paper No. 2000-02-0515, 5: I.S.Abdul-Khalek et al ,Diesel Exhaust Particle Size: Measurement Issues and Trends, SAE Paper No. 980525 , 6: David Kittelson et al, 2000. Diesel Aerosol Sampling in the Atmosphere. SAE Technical Paper Series, 2000-02-2212 ,7: D.B.Kittelson, On-Road Measurements of Spark Ignition Nanoparticle Emissions,5th ETH Conference on Nanoparticle Measurement, 7th August 2001, 8:Rainer.Vog et al,,Nanoparticle formation in diesel vehicle exhaust: a comparison of laboratory and chasing experiments, 5th ETH Conference on Nanoparticle Measurement

PM size measurement to simulate the atmospheric dilution

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Objective

- Optimize the measuring method of real world PM size distribution from vehicles

Real world : Short time after tailpipe emission

Secondary aerosol formation is not included

Presentation overview

- Measurement of PM size distribution

1. in the ambient air (Chasing Exp.)
2. in the laboratory

   Reproduction of PM size in the ambient air

   1. Full Flow Dilution Tunnel (CVS)
   2. Simple frame wind tunnel
   3. Prototype partial flow diluter
3. Conclusion

Test vehicle and fuel specifications

- Test Vehicle
  - Light duty diesel truck
  - DI,4.5L,GVW 4,540kg
    (Tested weight 3,540kg)
  - Meeting Regulation 1998
- Fuel
  - Diesel fuel JIS NO2
  - Sulfur 0.039wt%

Measuring Instrument

- Scanning Mobility Particle Sizer
  - DMA(differential Mobility Analyzer + CPC(Condensation Particle Counter)
    - 90sec/1data scan) 10nm to 400nm
    - TSI Model 3081 + 3025

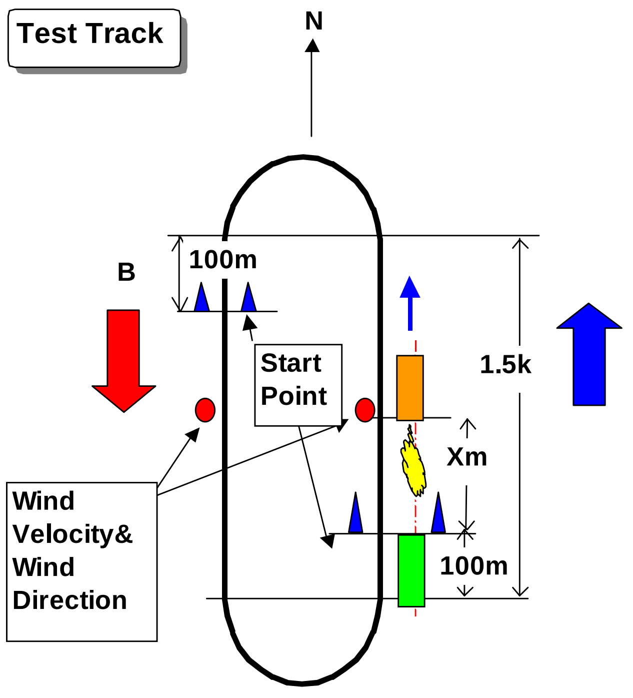
Definition

- Dilution ratio : DR

  $= [NOx_{exhaust} - NOx_{background}] / [NOx_{sample} - NOx_{background}]$

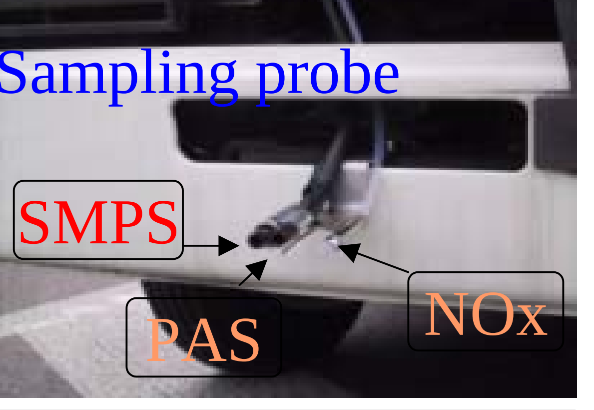
- PM size distribution
  - usually corrected with DR for comparison to relevant tailpipe concentration
  - "x DR" is indicated
- Total PM = $\Sigma dN/d\log Dp$ / 64
  - SMPS 10nm to 400nm

1. Chasing Experiment



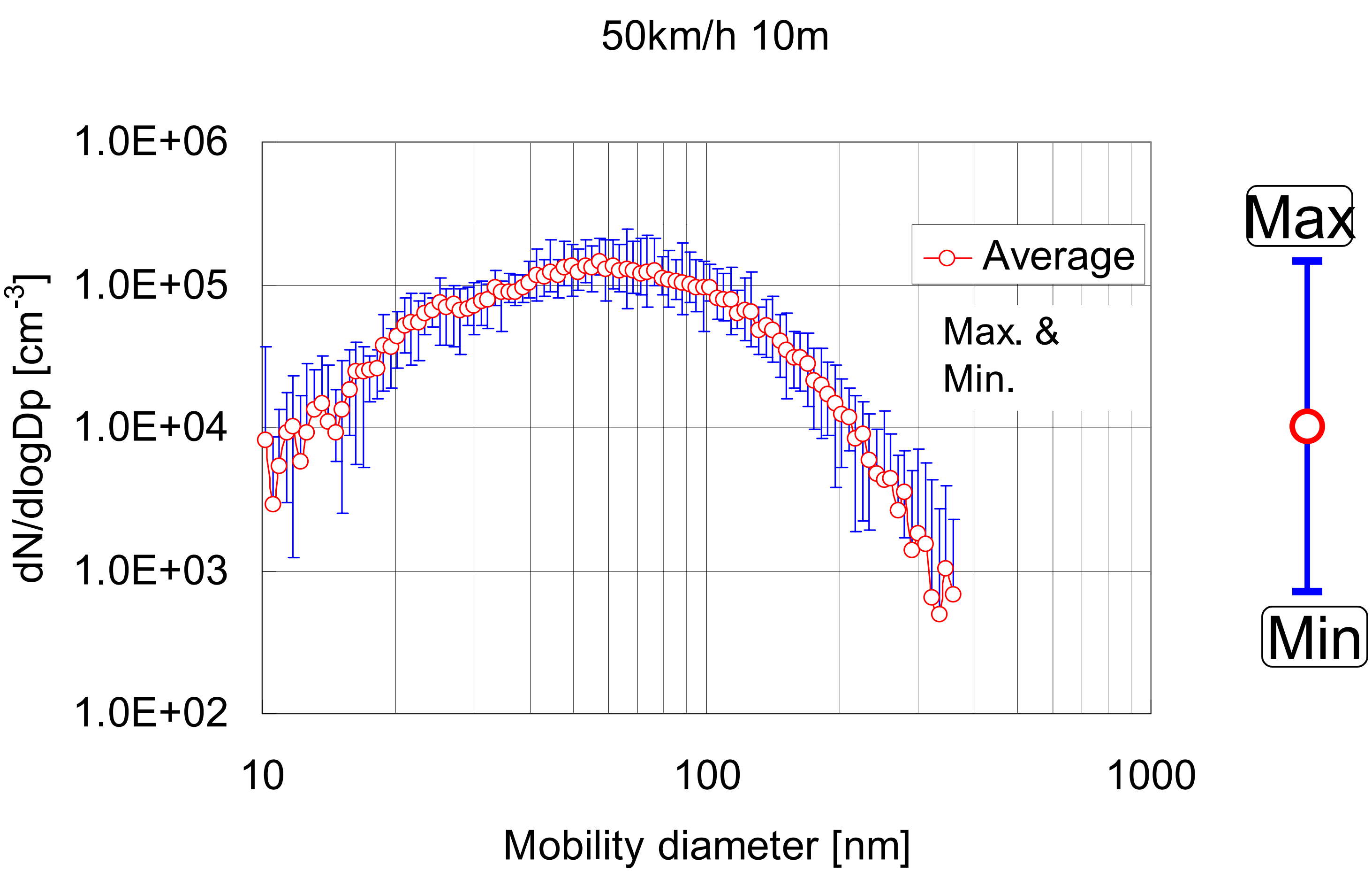
Steady state (half load)

20kph, 50kph, 80kph

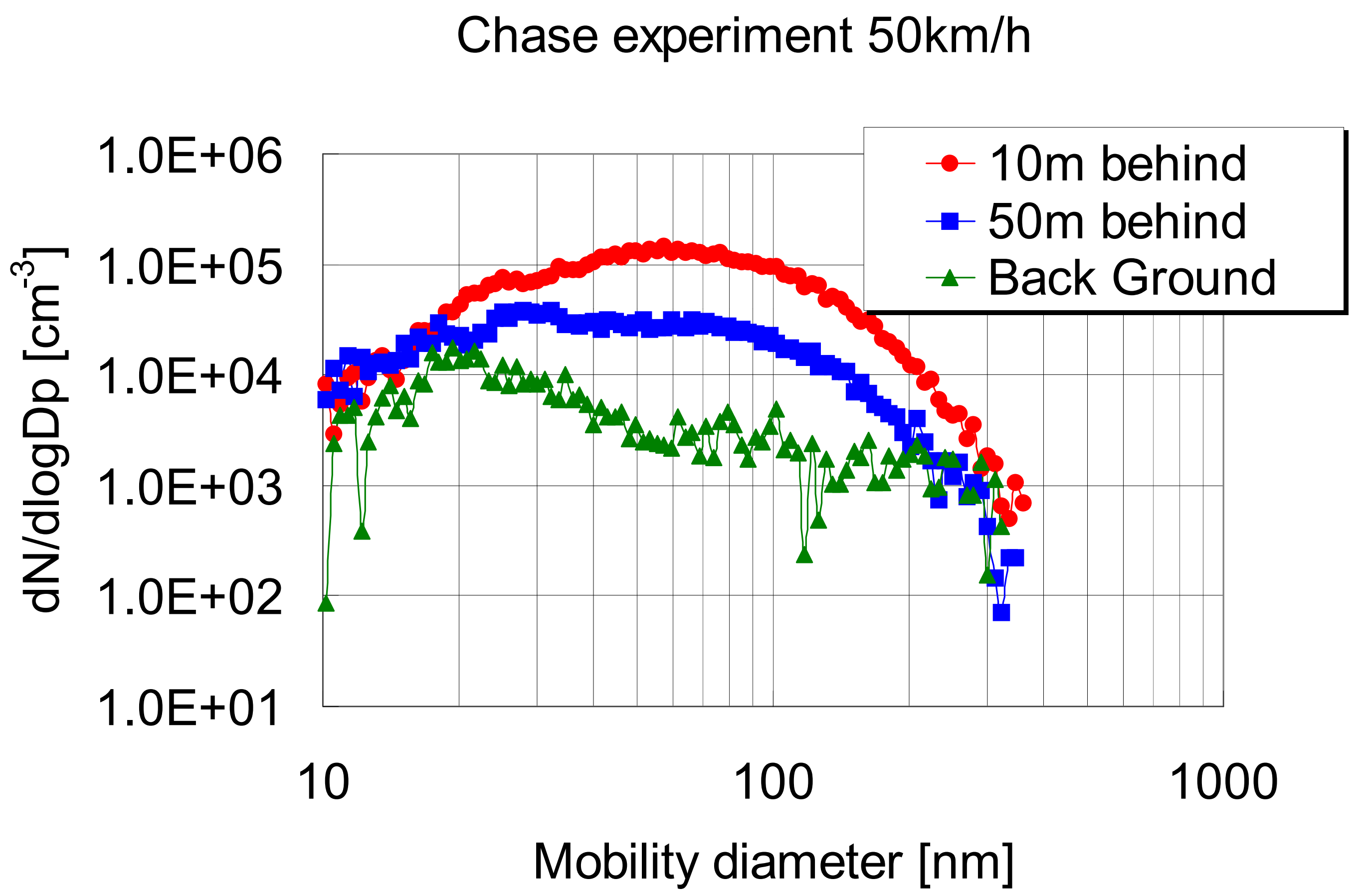


Example of chasing data

Averaging 10 data

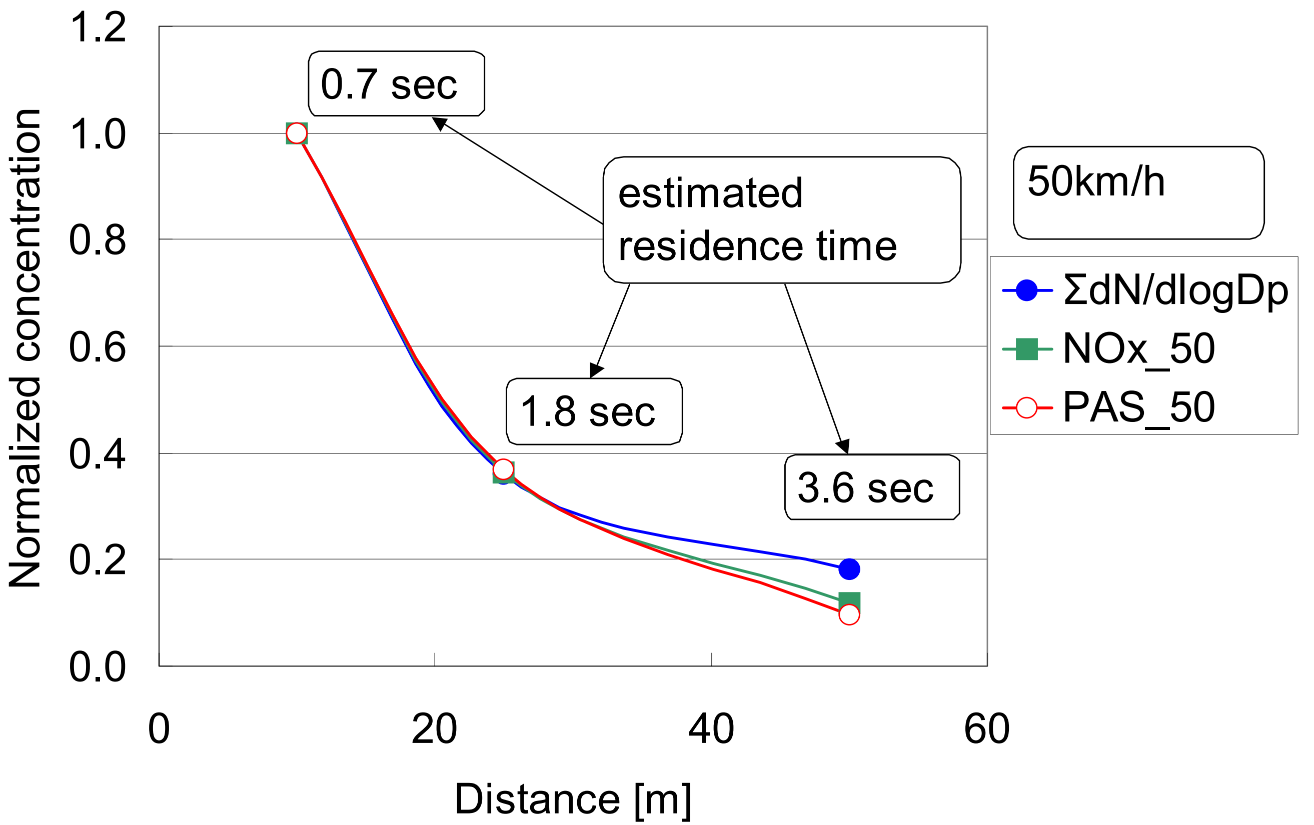


Raw data



Chase experiment 50km/h
10m behind
50m behind
Back Ground
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
dN/dlogDp [cm-3]
10
100
1000
Mobility diameter [nm]

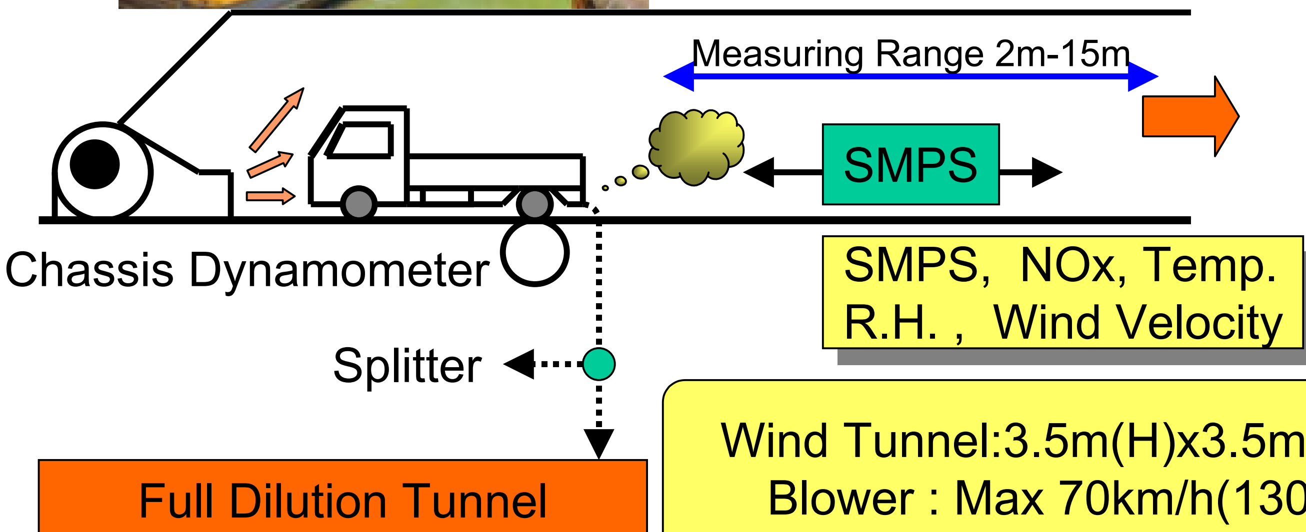
Attenuation



Dilution Ratio

	Test vehicle		Exhaust gas		Test track	
Vehicle Speed	Distance	Dilution Ratio (by NOx)	Residence Time	Temp.	Relative Humidity	Atmos-pheric pressure
km/h	m		sec	°C	%	hPa
20	BG			20	68	1011
	10	1500	1.8	20	67	1011
	50	11000	9.0	20	62	1011
50	BG			21	59	1011
	10	2020	0.7	21	57	1011
	25	5240	1.8	23	50	1011
	50	9340	3.6	23	52	1011
80	BG			23	51	1011
	50	4360	2.3	20	61	1011
	100	8120	4.5	22	54	1011

2. Simple frame Wind tunnel



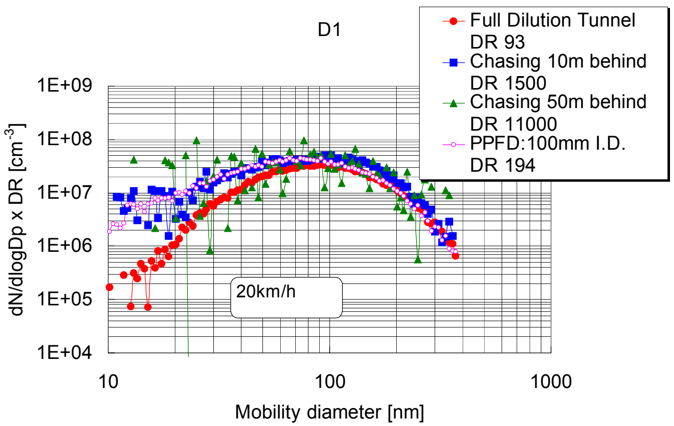
Wind Tunnel:3.5m(H)x3.5m(w)x20m(L)
Blower : Max 70km/h(1300m^3/min)

3. Prototype Partial Flow Diluter
for investigation of dilution processes

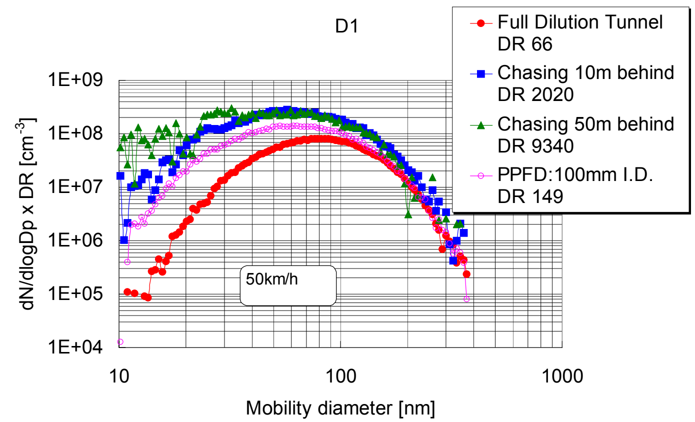




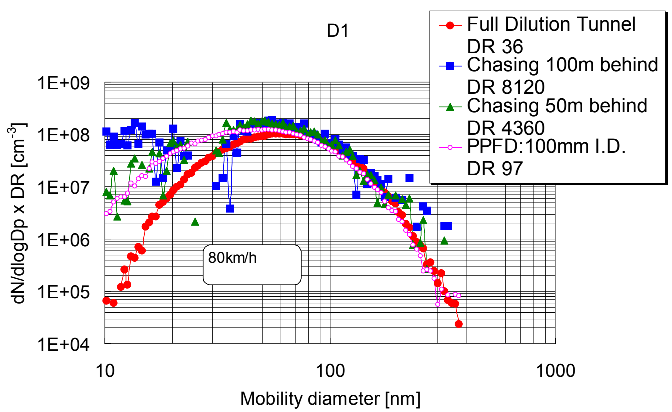

Comparison



D1
Full Dilution Tunnel DR 93
Chasing 10m behind DR 1500
Chasing 50m behind DR 11000
PPFD:100mm I.D. DR 194
20km/h
dN/dlogDp x DR [cm-3]
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
10
100
1000
Mobility diameter [nm]

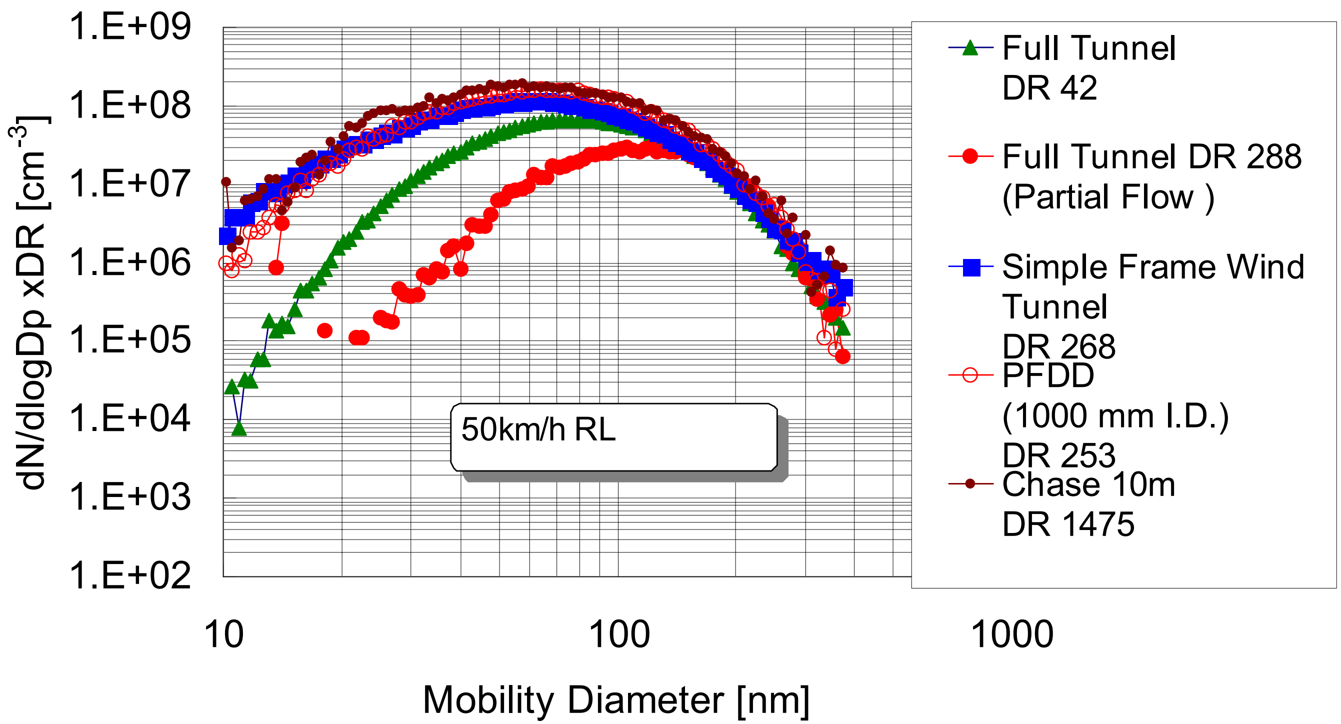


D1
Full Dilution Tunnel DR 66
Chasing 10m behind DR 2020
Chasing 50m behind DR 9340
PPFD:100mm I.D. DR 149
50km/h
dN/dlogDp x DR [cm-3]
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
10
100
1000
Mobility diameter [nm]



D1
Full Dilution Tunnel DR 36
Chasing 100m behind DR 8120
Chasing 50m behind DR 4360
PPFD:100mm I.D. DR 97
80km/h
dN/dlogDp x DR [cm-3]
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
10
100
1000
Mobility diameter [nm]

Comparison of PM size distribution
with various dilution methods

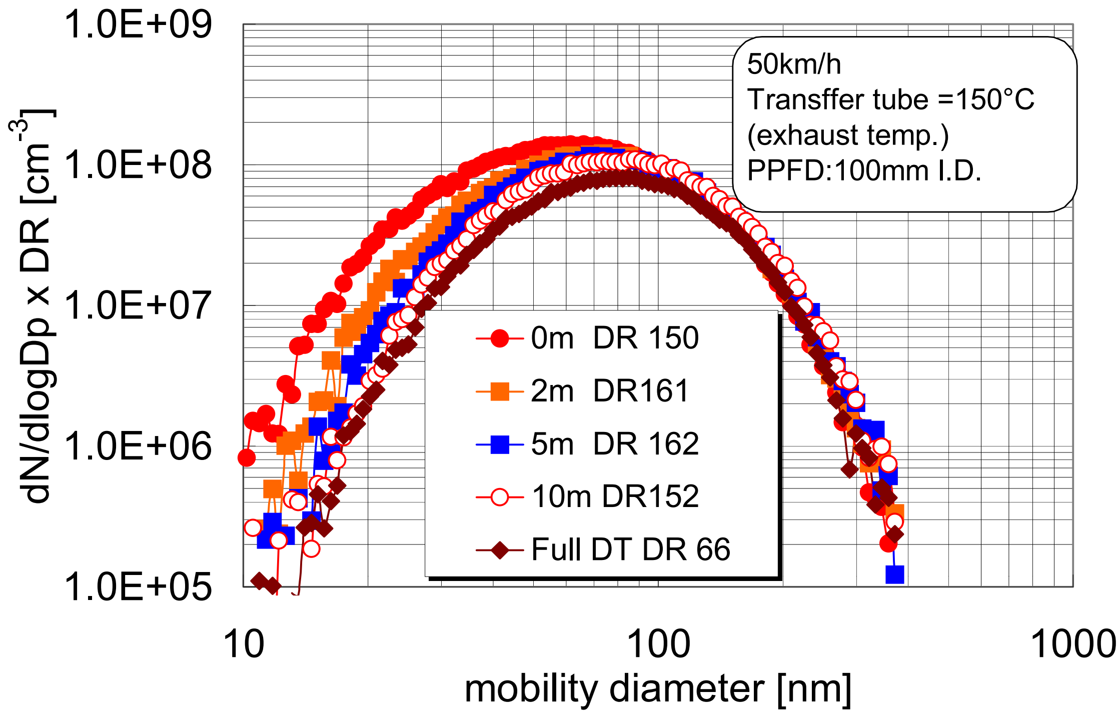


What cause the differences ?

- Dilution ratio ?
- Relative humidity ?
- The orifice of the dilution tunnel ?
- Residence time of undiluted exhaust gas?

The length of the transfer tube greatly affects PM size

Residence time : 0 to 1.3 sec (10 m)



Conclusion

- Residence time of undiluted exhaust gas greatly affects smaller side of PM size.
- PPFD approximately reproduces PM size distribution from a vehicle
- FFDT could reproduce PM size distribution in the atmosphere by reducing the residence time of undiluted exhaust

Further Study

- Establishment of the calibration method for PM size and number
- Application for transient mode
- Size classified chemical analysis
- PM sizing of various kind of vehicles.