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MEASUREMENT OF EXHAUST EMISSIONS FROM LIGHT DUTY DIESEL ENGINED VEHICLES

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MEASUREMENT OF EXHAUST EMISSIONS FROM LIGHT DUTY DIESEL ENGINED ROAD VEHICLES

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SUMMARY

Particulate and gaseous exhaust emissions were measured on a sample of six diesel engined road vehicles of less than 3.5 tonnes gross vehicle weight. Measurements were made in the laboratory and on the road over a wide range of operational conditions including ECE 15 and US Federal test drives, steady state drives at several speeds and rural, urban and motorway drives over prescribed routes.

All of the vehicles tested had gaseous emissions that were within the ECE Regulation 15-04 type approval limits: CO emissions were less than 10 per cent and combined HC and NOx emissions generally around 30 per cent of the limit values. It was estimated that the pre and post 1987 US particulate standards (0.6 and 0.2 g/mile) would be equivalent to about 0.44 g/km (1.78 g/test) and 0.15 g/km (0.61 g/test) respectively over the ECE 15 test. Only one vehicle (a directly injected vehicle) emitted more than 0.44 g/km whereas only one vehicle emitted less than 0.15 g/km.

The variation of emission rates with vehicle speed was examined and it was shown that the average CO emissions from all six vehicles fell as the road speed increased, with some evidence from two vehicles of an upturn at the highest speed. NOx emissions in general also became lower as the speed increased. The general trend of particulate emissions was to fall with increasing speed. Some cars showed an increase at higher speeds.

Visible smoke was also measured during the dynamometer tests but no relationship was observed between smoke and the rate of mass emission of particulates.

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1. INTRODUCTION

It is the intention of the European Commission (EC) to limit particulate emissions from light-duty vehicles equipped with diesel engines. The EC have agreed a limit of 1.1 g $test^{-1}$ at the type approval stage and 1.4 g $test^{-1}$ for conformity of production. The emissions of particulates from a diesel engined vehicle are strongly influenced by driving characteristics, engine speed, load, engine temperature etc and very few data are available to enable the implications of the imposed limit to be assessed.

Warren Spring Laboratory (WSL) was commissioned by the Transport and Road Research Laboratory of the Department of Transport to measure particulate emissions from a sample of current light-duty diesel engined vehicles in accord with ECE R15 and US Federal test procedures.

In order to measure emissions over a wide range of operating conditions, experiments were also conducted under normal road operating conditions using an on-board Mini-CVS[1] modified to include a miniature dilution tunnel.

2. EXPERIMENTAL

2.1 Test Vehicles

In accord with the proposals of the EC, light-duty vehicles were defined as having a gross weight not exceeding 3.5 tonnes. Six vehicles were obtained on short term hire. Where possible the specification required was:

i) Less than one year old
ii) Less than 10,000 recorded miles.

These criteria were met on all vehicles except one.

There is still only a limited choice of light-duty vehicles available in the short term hire fleets which are fitted with the diesel engine option. It was possible, however, to obtain a reasonable selection of six vehicles for this investigation. Four of the vehicles used are available in saloon, estate and commercial versions with carrying capacities of 250-500 kg. The two largest vehicles are purely commercial vehicles available in the 2.5-3.5 tonnes gross vehicle weight range. The test vehicles were both over 3 tonnes gross vehicle weight.

Details of the vehicles used are given in Table 1 below.

TABLE 1. - Vehicle Characteristics

Vehicle	Odometer Miles	No of Cyls	Engine Capacity litres	No of Gears	Kerbweight kg
A	3,551	4	1.6	5	940
B	5,680	4	1.6	5	1010
C	58,310	4	2.3	5	1230
D	5,500	4	1.8	5	900
E*	551	4	2.5	4+O/D	1570
F	6,853	4	2.5	5	1650

* All vehicles indirect injection except E which was directly injected.

2.2 Test Programme

The programme for each vehicle comprised 58 tests as follows:

2.2.1 Road Tests

Cross country drives	4 tests
Urban drives	6 tests
Motorway drives 90 km h^{-1}	6 tests
Motorway drives 110 km h^{-1}	6 tests
Total road tests	22 tests

2.2.2 Dynamometer Tests

Cold-start tests to ECE R 15-04	4 tests
Hot-start tests to ECE R 15-04	8 tests
US Federal cycle - Cold Start	4 tests
US Federal cycle - Hot Start	8 tests
Steady-State drive 50 km h^{-1}	4 tests
Steady-State drive 70 km h^{-1}	4 tests
Steady-State drive 90 km h^{-1}	4 tests
Total dynamometer tests	36 tests

In addition "smoke" was measured from each vehicle for the three steady state and the two hot-start cycle conditions.

2.3 Methodology

2.3.1 Dynamometer Tests

The dynamometer tests were carried out in accord with the prescriptions of ECE R15-04[2] and the 1980 US Federal Register[3]. The chassis dynamometer was equipped with 508 mm diameter rolls and power absorbtion was by a DC motor/ generator set. The dynamometer settings were positioned for each vehicle such that coast-down times, measured on the dynamometer, were the same as those obtained when running the vehicle on the road.

For the steady state tests the 50 km h^{-1} runs were carried out in 3rd gear. The decision to use this gear was taken before the vehicles to be tested had been chosen. It was considered that all vehicles within the specified size range would run effectively in this gear but not necessarily in a higher gear. 70 and 90 km h^{-1} tests were conducted in 4th gear.

2.3.2 Smoke Measurements

Smoke measurements were made using a Hartridge Mk III Smokemeter.

A light source and a photocell are mounted on a frame within the instrument at a fixed distance apart. By rotating this frame a beam of light was projected onto the photocell down one of two tubular pathways. One pathway was constantly purged with ambient air and the other with vehicle exhaust gases. By selecting an appropriate sized probe inserted into the vehicle exhaust, sufficient exhaust gases were sampled to ensure that the light path was properly filled.

The instrument was zeroed on the air-filled light path and the light obscuration measured on the exhaust gas-filled pathway.

For the steady state tests, spot readings were taken in absolute smoke units, from the instrument analogue read-out. The outputs from the cyclic tests were recorded on a chart recorder and integrated at a later date to provide an average smoke unit figure for each type of cycle.

2.3.3 Road Tests

The on-the-road emissions were measured using the WSL Mini-CVS system with a 112 tube flow splitter. Exhaust gases from one tube entered the Mini-CVS and were diluted with ambient air. The diluted exhaust gases were then passed into a miniature dilution tunnel to ensure complete mixing. At the end of the dilution section a sub-sample was taken for particulate measurement and, after filtration, a further sample was taken from the main stream for gaseous analysis. A schematic diagram of the equipment is given in Fig. 1.

During the dynamometer tests referred to previously the Mini-CVS was operated in parallel with the standard CVS unit, with suitable corrections made for the diverted exhaust gases. Thus results obtained from the Mini-CVS were regularly verified against the standard CVS system. Each vehicle's test schedule was arranged, so that verification tests were carried out both before and after the road test periods. A schematic diagram of the system is given in Fig. 2.

Cross-country and urban driving tests were carried out on specified test routes previously used by WSL for vehicle exhaust emission tests. A description of the test routes is given in Appendix A. Driving patterns during the tests were dictated by prevailing traffic conditions and statutory controls. All gears were used for these tests, gear selection being made according to prevailing driving conditions.

On the motorway drives, 90 km h^{-1} was driven in 4th gear and 110 km h^{-1} in 5th gear. Each drive was carried out using minimum throttle movements to maintain the target speed. Enforced throttle movements, due to traffic or topographical changes, were made as slowly as possible to reduce the rates of acceleration and deceleration to a minimum consistent with safe driving. Each set of six results consisted of three drives in each direction over the same section of motorway.

3. RESULTS AND DISCUSSION

3.1 Compliance with ECE Regulation 15-04

The measured mean emissions of carbon monoxide (CO), hydrocarbons (THC) and oxides of nitrogen (NOx) from all six vehicles are given in Table 2 together with the percentage compliance of each emission with the current ECE R15-04 type appoval regulation.

All of the vehicles tested had gaseous emissions that were within the ECE R15-04 type approval limits. In the case of CO emissions all six vehicles emitted less than 10% of the limit value. For example vehicle C emitted 3.50 g $test^{-1}$ whereas the appropriate limit is 67 g $test^{-1}$. Combined THC and NOx emissions were generally about 30% of the limit value. The direct injection engined vehicle emitted the highest levels of CO and combined THC/NOx ie 9.7% of the CO limit and 70% of the combined THC/NOx limit.

3.2 Comparison of Particulate Emissions for ECE and US Federal Tests

The mean particulate emissions for the ECE and US Federal cold start tests are given in Table 3. For five out of six of the vehicles tested, more particulates were produced during the ECE cycle. The mean ratio ECE/US = 1.19 with standard deviation 0.26.

These results suggest that a particulate emission limit of ~0.44 g km^{-1} (1.78 g/test) applied to an ECE driving cycle would be equivalent to the US EPA 0.6 g $mile^{-1}$ (0.37 g km^{-1}) limit applied to the US Federal drive cycle. The 1987 reduction in the US EPA limit to 0.2 g $mile^{-1}$ (0.125 g km^{-1}) approximates to an ECE limit of ~0.15 g km^{-1} (0.61 g/test).

All of the vehicles tested except Vehicle E (the direct injection engined vehicle) would meet a limit of 0.44 g km^{-1} for the ECE driving cycle but both of the two largest vehicles (E&F) failed to meet the pre-1987 US EPA limit for the Federal driving cycle. Only vehicle A would meet the more stringent ECE limit based on the current US EPA limit, but none actually met the current US EPA limit although vehicle A was close to it.

A comparison of particulate emissions for the ECE and US Federal cycles hot start tests are given in Table 4. In this case the ratio ECE/US = 1.04.

3.3 Variations of Emissions with Driving Cycle

3.3.1 Dynamometer Tests

A summary of mean gaseous and particulate pollutant emission rates is given in Table 5. In general, vehicles emitted pollutants at a higher rate during the ECE R15 cycle than during the US EPA cycle. However, it should be noted that vehicle A emitted 0.08 g km^{-1} of particulate matter during the hot start ECE R15 cycle whereas the emission rate was 0.12 g km^{-1} during the US EPA cycle; also, vehicle F particulate emissions were higher during the US EPA cycle than during the ECE R15 cycle.

TABLE 2. - Conformity of Gaseous Emissions with ECE R15-04 Type Approval Standards

Vehicle	Odometer miles	No of Tests	Emissions, g $test^{-1}$			Fuel Consumption l $(100\ km)^{-1}$	Compliance % of Standard		ECE R15 Limit Values	
			CO	THC	NOx		CO	THC + NOx	CO	THC + NOx
A	3500	4	3.24	1.45	3.49	7.45	5.6	26.0	70	23.8
B	5680	4	5.14	1.98	2.94	9.68	8.9	25.9	70	23.8
C	58000	4	3.50	0.81	5.84	9.51	5.2	32.0	80	25.6
D	5500	4	3.84	1.14	2.83	7.03	6.6	20.9	70	23.8
E	550	4	8.16	5.37	11.09	10.70	9.7	70.0	101	29.4
F	6850	4	6.84	1.72	5.18	11.88	7.4	27.6	101	29.4

TABLE 3. - Comparison of Particulate Emissions from ECE and US Federal Cycle Cold Start Tests

Vehicle	Particulate Emission g km^{-1}		Ratio ECE/US
	ECE	US	
A	0.14	0.13	1.08
B	0.25	0.19	1.32
C	0.19	0.16	1.19
D	0.18	0.16	1.13
E	1.11	0.70	1.59
F	0.41	0.50	0.82
	Mean Ratio		1.19
	Standard Deviation		0.26

For the ECE "Hot Start" cycle the rates of all pollutant emissions were significantly less than for the "Cold" tests. This was expected because the engines were never fully warmed up during the ECE "Cold" tests, the final engine oil temperature being lower than that at the start of the "Hot" tests.

TABLE 4. - Comparison of Particulate Emissions from ECE and US Federal Cycle Hot Start Tests

Vehicle	Particulate Emission g km^{-1}		Ratio ECE/US
	ECE	US	
A	0.08	0.12	0.67
B	0.22	0.19	1.16
C	0.17	0.14	1.21
D	0.18	0.15	1.20
E	0.85	0.73	1.16
F	0.39	0.47	0.83
	Mean Ratio		1.04
	Standard Deviation		0.23

In the US Federal tests, due to the higher engine speeds, the vehicles reached working temperature during the cold start cycle and the added duration reduced any effects of the initial cold start. There was little difference between "Hot" and "Cold" start tests for most pollutants.

At 70 km h^{-1} a higher gear (4th) was engaged and the emission rate of all pollutants predictably fell because the engine revolutions per kilometer were

TABLE 5. - Summary of Gaseous and Particulate Emissions on the Dynamometer

Test	Emissions, g km^{-1}			
	CO	THC	NOx	PART
	Vehicle A			
ECE (cold)	0.81	0.36	0.87	0.14
ECE (hot)	0.64	0.29	0.76	0.08
US (cold)	0.53	0.20	0.55	0.13
US (hot)	0.51	0.21	0.54	0.12
50 km h^{-1}	0.49	0.17	0.42	0.07
70 km h^{-1}	0.39	0.13	0.41	0.12
90 km h^{-1}	0.35	0.19	0.45	0.13
	Vehicle B			
ECE (cold)	1.28	0.49	0.73	0.25
ECE (hot)	1.13	0.41	0.68	0.22
US (cold)	0.93	0.30	0.67	0.19
US (hot)	0.87	0.32	0.62	0.19
50 km h^{-1}	1.02	0.47	0.51	0.23
70 km h^{-1}	0.49	0.19	0.36	0.09
90 km h^{-1}	0.44	0.13	0.35	0.08
	Vehicle C			
ECE (cold)	0.87	0.20	1.45	0.19
ECE (hot)	0.76	0.16	1.45	0.17
US (cold)	0.60	0.11	1.15	0.16
US (hot)	0.54	0.08	1.08	0.14
50 km h^{-1}	0.22	0.03	1.12	0.06
70 km h^{-1}	0.16	0.05	1.11	0.06
90 km h^{-1}	0.15	0.03	0.89	0.05
	Vehicle D			
ECE (cold)	0.96	0.28	0.70	0.18
ECE (hot)	0.90	0.18	0.60	0.18
US (cold)	0.53	0.11	0.49	0.16
US (hot)	0.56	0.08	0.54	0.15
50 km h^{-1}	0.51	0.07	0.43	0.14
70 km h^{-1}	0.36	0.06	0.39	0.12
90 km h^{-1}	0.43	0.06	0.32	0.14
	Vehicle E			
ECE (cold)	2.03	1.33	2.76	1.11
ECE (hot)	1.59	0.91	1.17	0.85
US (cold)	1.34	0.77	1.14	0.70
US (hot)	1.33	0.67	1.05	0.73
50 km h^{-1}	1.17	0.87	0.70	0.96
70 km h^{-1}	0.87	0.59	0.69	0.71
90 km h^{-1}	0.78	0.43	0.80	0.54
	Vehicle F			
ECE (cold)	1.70	0.43	1.29	0.41
ECE (hot)	1.30	0.23	1.31	0.39
US (cold)	1.33	0.38	1.19	0.50
US (hot)	1.11	0.30	1.12	0.47
50 km h^{-1}	0.99	0.28	0.84	0.52
70 km h^{-1}	0.58	0.18	0.88	0.39
90 km h^{-1}	0.77	0.24	1.39	0.29

proportionately reduced. As the speed was increased to 90 km h^{-1} the effects on emission rates varied. On four vehicles the overall effect was a slight fall in emissions which is consistent with improved combustion at the higher temperatures prevailing. However, in the cases of the other two vehicles the particulate emission rates increased indicating that combustion conditions may have passed the optimum point.

3.3.2 Comparison Between Dynamometer and Road Emissions

In most cases the ECE "Hot Start" tests gave higher rates of emission of all pollutants than those measured on the road during the urban drives. The significant exception were the particulate emissions from vehicle A which gave the lowest measured values of all vehicles tested, on the dynamometer, but were the highest measured values on the road with the exception of the direct injection-engined vehicle. Emissions of CO and NOx were not affected to the same degree. Thus the CO emissions measured on the road were ~9 per cent higher than on the dynamometer whereas the NOx emissions on the road were ~52% lower than measured on the dynamometer.

A plot of the ECE (Hot Start) emission against the urban cycle emission for particulates is given in Fig. 3. The "ideal" ratio 1:1 is indicated by the full line on the plot. Vehicle A is clearly an outsider, the ECE cycle value being only 22.5% of the urban emission. Vehicles B, C and D lie closer to the 'ideal' line and for these vehicles the ECE cycle results are 138%, 79% and 120% respectively of the urban drive results. For the two larger vehicles the ECE cycle was greater than the urban emissions by 28% and 62% respectively probably due to the low gear ratios and the use of the higher gears on the road drive.

The cross country tests were typically carried out at an average speed of 55-60 km h^{-1}. All gears were used as appropriate to the traffic conditions.

Running in higher gears and with less occasions of acceleration and deceleration the cross-country tests predictably showed a marked decrease in the emission rates of all pollutants over the urban drives.

The 90 km h^{-1} steady state tests were carried out in 4th gear as were the dynamometer tests at this speed. Emission rates were of the same order on both given the small number of tests being considered for each vehicle.

The 110 km h^{-1} tests were carried out in 5th gear (overdrive 4th in vehicle E). Several of the vehicles, especially the two largest vans had some difficulty in maintaining this highest speed. All but the two smallest engined vehicles showed a decrease in particulate emission rate at the higher speed.

3.3.3 Variation of Particulate Emission Rates with Vehicle Speed

The rate of particulate emissions against average vehicle speed on the road, for all six vehicles, is shown plotted in Fig. 4. Plots for each vehicle in alphabetical order are shown in Figs 5-10. The general trend is, as reported in previous work[1], for the emission rate to fall as the average speed increases. For four of the vehicles, the emission rate measured at 90 km h^{-1} did not show a fall over those measured at the previous lower speed. The probable explanation for this was that 4th gear was selected for the 90 km h^{-1} tests whilst in normal driving practice 5th gear would have been selected with corresponding reductions in emissions of pollutants at the lower engine speeds. Emissions from five vehicles at the highest test speed were similar to or slightly higher than the minimum. Emissions from the excepted vehicle (E) fell consistently with increasing road speed. However, even at its minimum, vehicle E had particulate emissions almost as large as any other vehicle's maximum.

The urban drives were carried out at an average speed of around 20 km h^{-1}. Mean particulate emission rates measured ranged from 0.15-0.35 g km^{-1} for the indirect injection engined vehicles and 0.67 g km^{-1} for the direct injection engined vehicle.

Cross-country drives were driven at average speeds 55-66 km h^{-1} and mean particulate emission rates for the indirect injection engined vehicles ranged from ~0.08 to ~0.25 g km^{-1}. Again the direct injection vehicle particulate emissions were higher (0.55 g km^{-1}).

As previously noted the 90 km h^{-1} motorway tests were run in 4th gear to repeat the dynamometer tests and that this gear was not necessarily the ideal gear selection for the speed. Particulate emission rates for the four smallest vehicles ranged from 0.10-0.20 g km^{-1}. Vehicle F showed a particularly large increase in emission rate at 0.35 g km^{-1} a clear indication that a higher gear selection was desirable. The direct inject vehicle emitted 0.41 g km^{-1}.

All 110 km h^{-1} tests were carried out in overdrive gear and particulate emission rates ranged from 0.08-0.24 g km^{-1} for the indirect injection vehicles and 0.28 g km^{-1} for the direct injection engine.

3.3.4 Variation of CO and NOx with Vehicle Speed

The mean emission rates of CO are plotted against average vehicle speed in Fig. 11 and the corresponding plot for NOx is shown in Fig. 12. Emission rates of both CO and NOx for the individual vehicles are given in Table 6.

The maximum emissions of CO occurred during the urban drives; the range of mean values was 0.53-1.06 g km^{-1} for the six vehicles. The highest mean CO values were measured from vehicle B (~1.06 g km^{-1}) at the lowest measured average urban road speed (~18.3 km h^{-1}). The average emissions CO from all six vehicles fell as the average road speed increased. For example, values in the range 0.19-0.44 g km^{-1} were measured from the indirect injection engined vehicles during the non-urban tests. The direct inject engined vehicle produced CO emissions in the range 0.53-0.72 g km^{-1} for the same tests. Both vehicles A and E showed evidence of an upturn in CO emissions at the highest speed (~110 km h^{-1}).

The mean values for NOx, from all vehicles, measured during the urban drive were in the range 0.49-0.94 g km^{-1}. In general, the mean rates of NOx emissions fell with mean vehicle speed but the overall effect was distorted by the enforced use of 4th gear for the 90 km h^{-1} drive even though this gear was not necessarily the best gear for the speed in practice and produced high engine speeds.

3.4 Smoke Emissions

The average smoke emissions from the six vehicles during the five dynamometer driving cycles are given in Table 7 together with the corresponding mass particulate emission value.

TABLE 6. - Summary of Gaseous and Particulate Emissions on-the-Road, g km^{-1}

Test	CO	NOx	PART	Ave Speed $km\ h^{-1}$	Gear(s) used
		Vehicle A			
Urban	0.70	0.50	0.35	20.0	All
Cross Country	0.36	0.37	0.25	60.6	All
Motorway 90 km h^{-1}	0.26	0.42	0.20	92.4	4
Motorway 110 km h^{-1}	0.32	0.35	0.24	111.1	5
		Vehicle B			
Urban	1.06	0.74	0.16	18.3	All
Cross Country	0.44	0.34	0.08	54.6	All
Motorway 90 km h^{-1}	0.42	0.45	0.10	86.3	4
Motorway 110 km h^{-1}	0.36	0.40	0.11	105.4	5
		Vehicle C			
Urban	0.65	0.94	0.22	22.6	All
Cross Country	0.34	0.70	0.11	57.9	All
Motorway 90 km h^{-1}	0.30	0.55	0.11	89.9	4
Motorway 110 km h^{-1}	0.19	0.43	0.09	108.5	5
		Vehicle D			
Urban	0.53	0.49	0.15	20.2	All
Cross Country	0.26	0.29	0.08	58.5	All
Motorway 90 km h^{-1}	0.29	0.34	0.12	90.1	4
Motorway 110 km h^{-1}	0.18	0.38	0.08	108.2	5
		Vehicle E			
Urban	0.86	0.83	0.67	21.6	All
Cross Country	0.72	0.66	0.55	61.6	All
Motorway 90 km h^{-1}	0.53	0.66	0.41	86.1	4
Motorway 110 km h^{-1}	0.68	0.77	0.28	101.1	O/D
		Vehicle F			
Urban	0.69	0.89	0.24	22.0	All
Cross Country	0.38	0.80	0.22	66.5	All
Motorway 90 km h^{-1}	0.56	0.99	0.35	94.0	4
Motorway 110 km h^{-1}	0.42	0.59	0.19	111.3	5

TABLE 7. - Smoke Emissions and Particulate Emission Rates

Test	ECE	US*	50 km h^{-1}	70 km h^{-1}	90 km h^{-1}
			Vehicle A		
Smoke	10	13.6	8	11	13
Part Emiss	0.08	0.12	0.07	0.12	0.13
			Vehicle B		
Smoke	15	14.5	13	15	14
Part Emiss	0.22	0.23	0.09	0.08	0.19
			Vehicle C		
Smoke	7	10.5	13	15	14
Part Emiss	0.17	0.06	0.05	0.05	0.14
			Vehicle D		
Smoke	10	13	16	17	18
Part Emiss	0.18	0.14	0.12	0.14	0.15
			Vehicle E		
Smoke	10	11.5	14	15	17
Part Emiss	0.85	0.96	0.71	0.54	0.72
			Vehicle F		
Smoke	7	6	5	5	6
Part Emiss	0.39	0.52	0.39	0.29	0.47

Note

1. The smoke emission for the US Federal test is based upon a simple average, not the weighted average used for the mass emission.

2. Particulate emission is expressed g km^{-1}.

3. Smoke expressed in Hartridge smoke units.

A plot of the particulate emission rate against smoke readings is given in Fig. 13. It can be seen that overall the particulate emissions and smoke are poorly correlated, although there may be a better correlation for individual vehicles. It is possible that unburnt hydrocarbons, being measured as particulate mass, are a cause of the poor correlation since these will cause reduced readings on the smoke meter. Also, for some vehicles, the smoke measurements were very low thus it was difficult to obtain accurate readings in a fluctuating output. No visible smoke was apparent during the driving cycles.

Peak values of smoke emission were typically 30-35 Hartridge units for the ECE cycle and 45-55 Hartridge units during the US Federal cycle.

4. CONCLUSIONS

1. Particulate and gaseous exhaust emissions were measured on six diesel engined vehicles of less than 3.5 tonnes gross vehicle weight.

2. All six vehicles tested complied with the ECE R15-04 Type Approval Test gaseous emission limits.

3. A comparison of ECE and US Federal driving cycles gave a particulate mass emission rate ratio ECE/US = 1.19 with standard deviation 0.26. An emission from the ECE cycle corresponding to the US Federal limit of 0.6 g $mile^{-1}$ would, on the basis of these measurements, be ~0.44 g km^{-1} (±0.10). Similarly a US limit of 0.2 g $mile^{-1}$ would equate to ~0.15 g km^{-1} (±0.03) on the ECE cycle.

   Five of the six vehicles tested would have met an ECE R15 limit based upon an emission rate of 0.44 g km^{-1} but only one would have met the more stringent limit of 0.15 g km^{-1}. It is important to note however that these tests were carried out on in-service vehicles which were tested as received.

4. With the exception of one vehicle (A) the ECE test cycle gave reasonable indication of particulate emission rates likely to be emitted by a vehicle being driven in an urban location. In most cases the emissions of particulates measured during the ECE R15 dynamometer cycle were higher than those measured on the road in an urban area. This was probably due to the selection of higher gear ratios on the road and hence lower engine speeds.

   In the case of vehicle A the ECE cycle produced mean particulate emissions which were on average 22% of those which were measured on the road during the urban drive. The reason for this difference was not known.

5. For the five indirect injection engined vehicles the relationship between rate of particulate emission and mean vehicle road speed was similar to that previously reported by Potter et al. The minimum emission rate occurred at an average speed in the range 50-60 km h^{-1}.

   Emissions from the direct injection engine fell from 0.67 g km^{-1} at an average speed of ~22 km h^{-1}, on the urban drive, to 0.28 g km^{-1} at the maximum test speed of 102 km h^{-1}.

5. REFERENCES

1. Potter, C.J., Savage, C.A. and Simmonds, A.C. The Development and Validation of an On-Board Diesel Particulates Sampler. Stevenage: Warren Spring Laboratory, 1986, LR 549 (AP)M.

2. Anon. United Nations. Economic Commission for Europe: Addendum 14: Regulation No 15, Revision 4, Geneva, 1985.

3. United States Federal Register Part III: Environmental Protection Agency: Standards for Emission of Particulate Regulation for Diesel-Fuelled Light-Duty Vehicles and Light-Duty Trucks, 1980.

6. ACKNOWLEDGEMENT

The work described in this report was carried out at WSL under contract to the Transport and Road Research Laboratory. It forms part of the programme of TRRL and the report is published by permission of the Director.

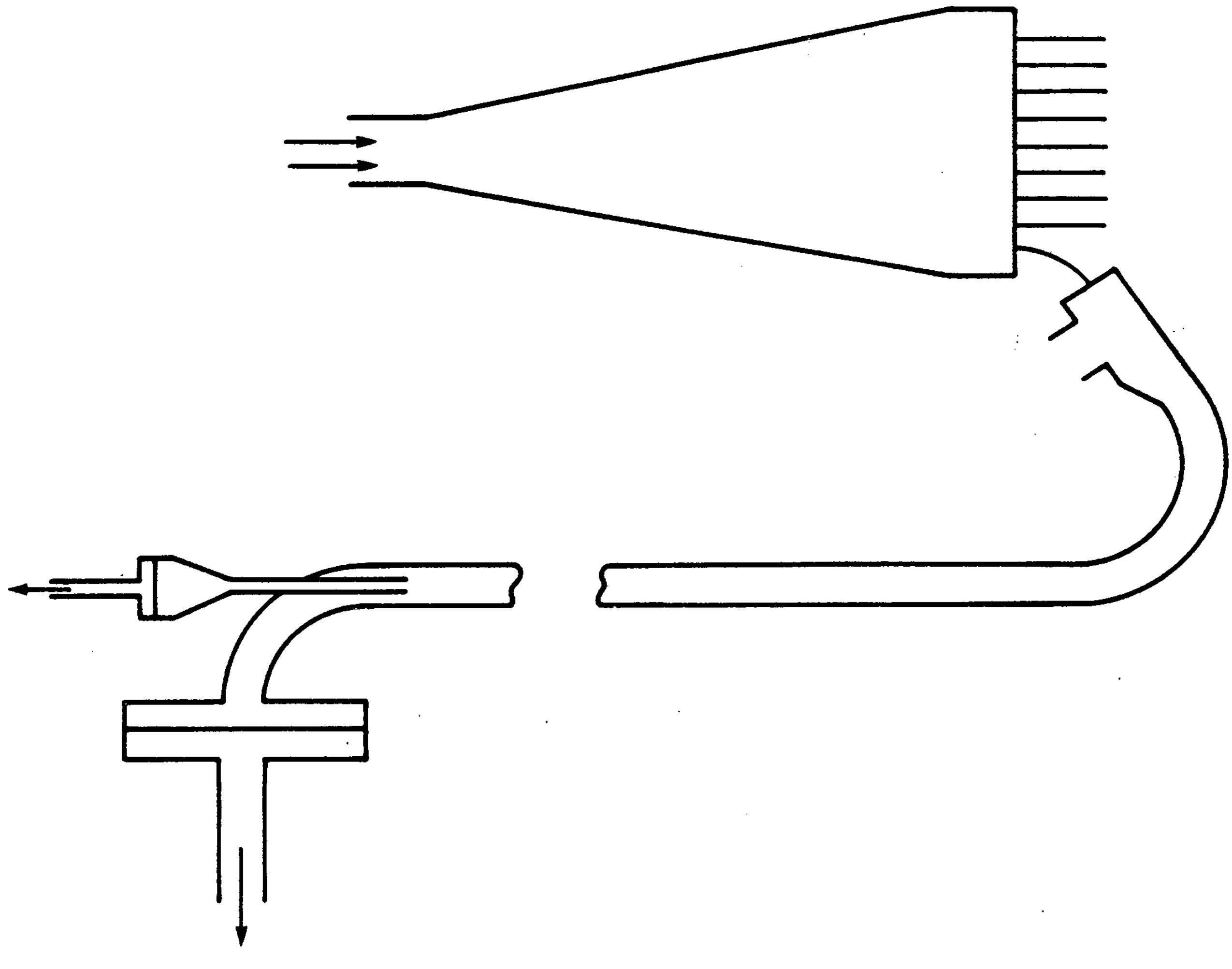

FIG. 1 SCHEMATIC ARRANGEMENT OF PARTICULATES SAMPLER FOR DIESEL ENGINES

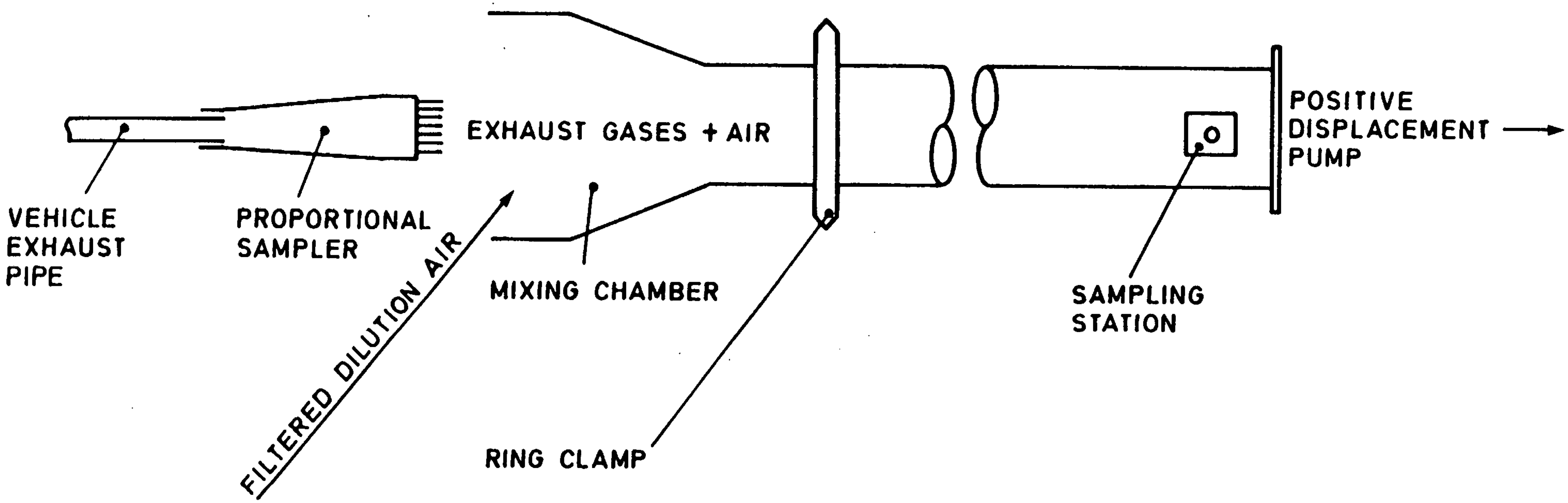

FIG. 2 SCHEMATIC ARRANGEMENT OF VEHICLE EXHAUST GAS DILUTION TUNNEL

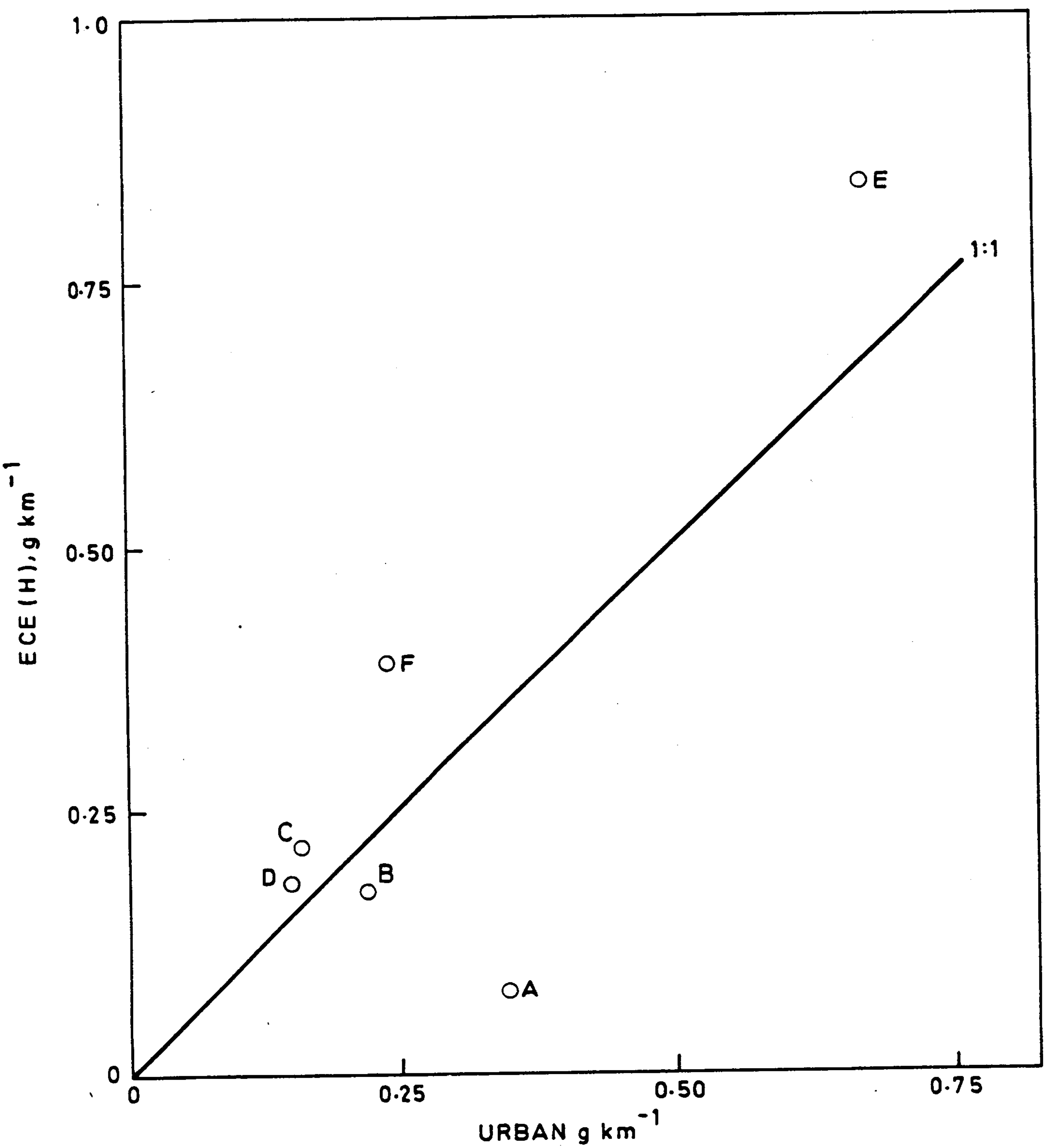

FIG.3 RELATIONSHIP BETWEEN PARTICULATE EMISSIONS ON THE ECE CYCLE AND URBAN DRIVE

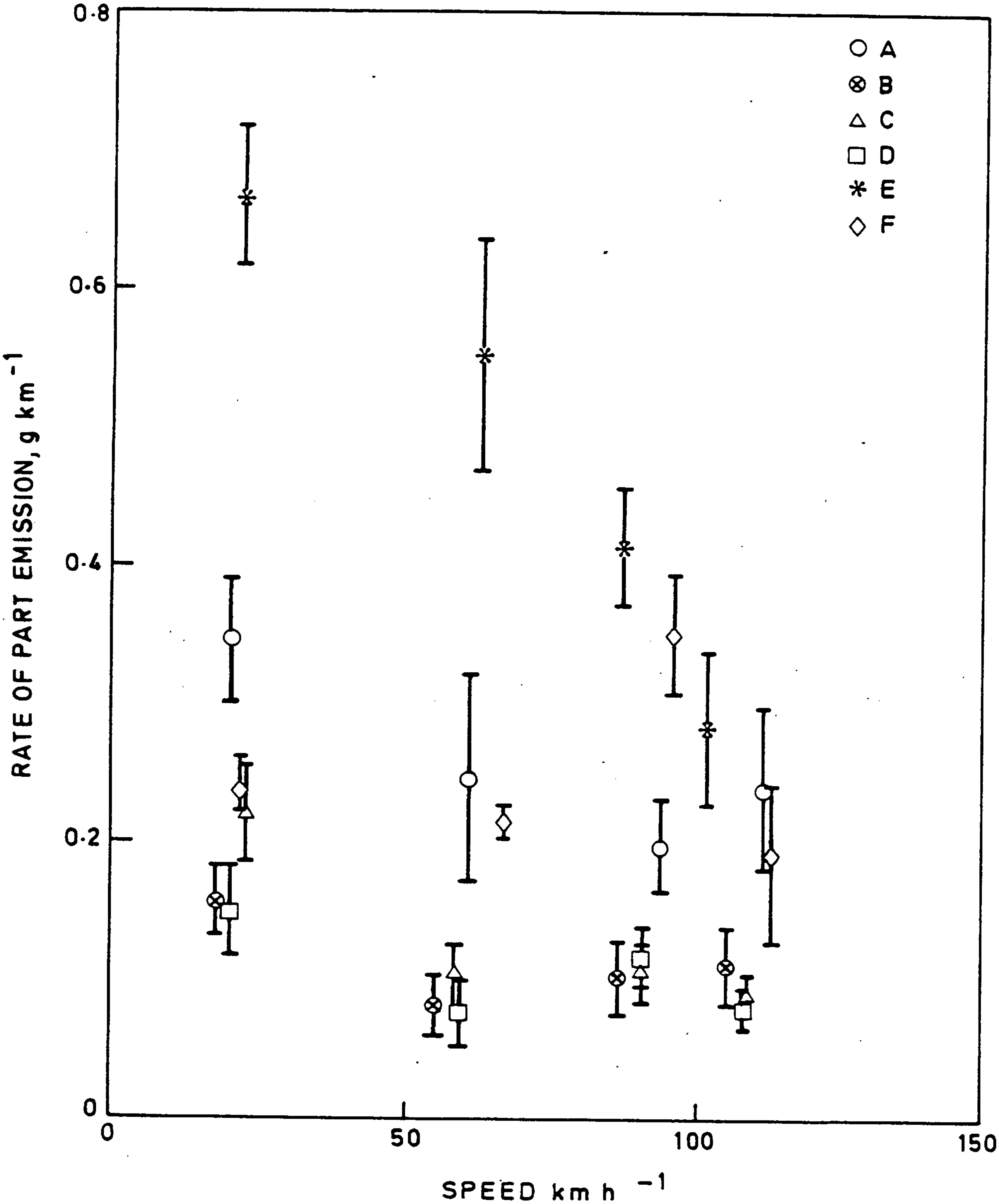

FIG.4 EMISSION OF PARTICULATES ON THE ROAD

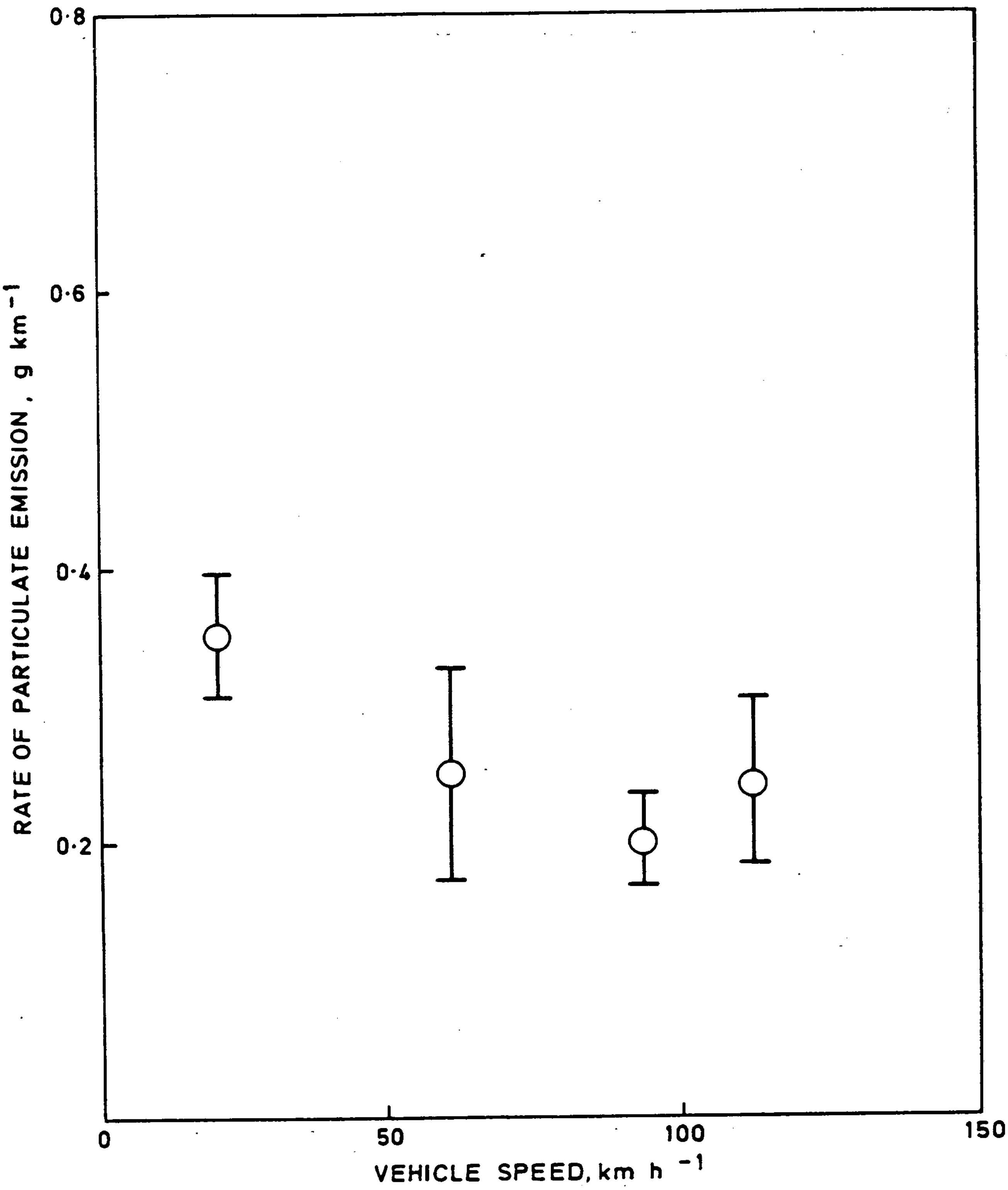

FIG. 5 VARIATION OF PARTICULATE EMISSION WITH VEHICLE SPEED. VEHICLE A

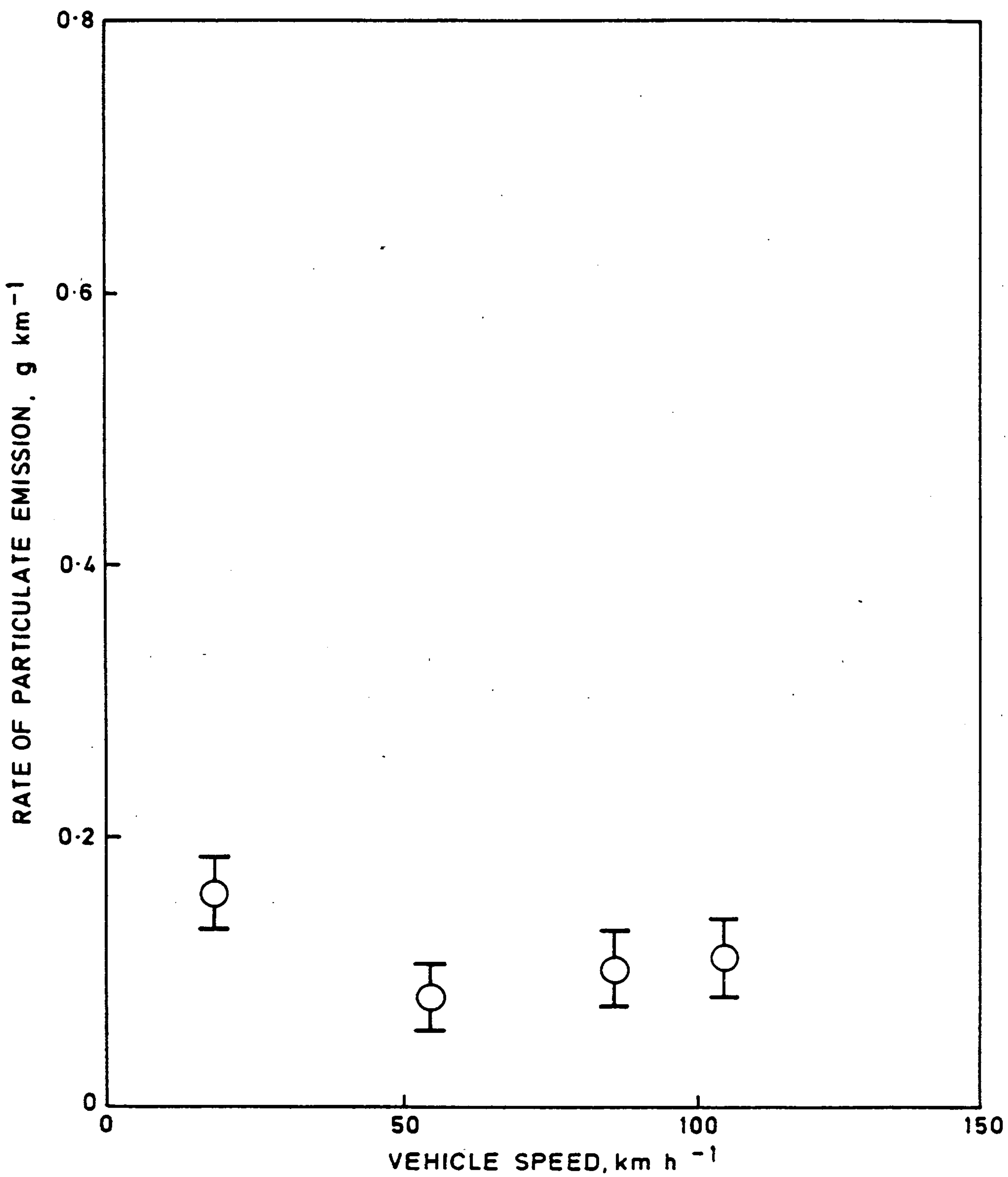

FIG. 6 VARIATION OF PARTICULATE EMISSION WITH VEHICLE SPEED. VEHICLE B

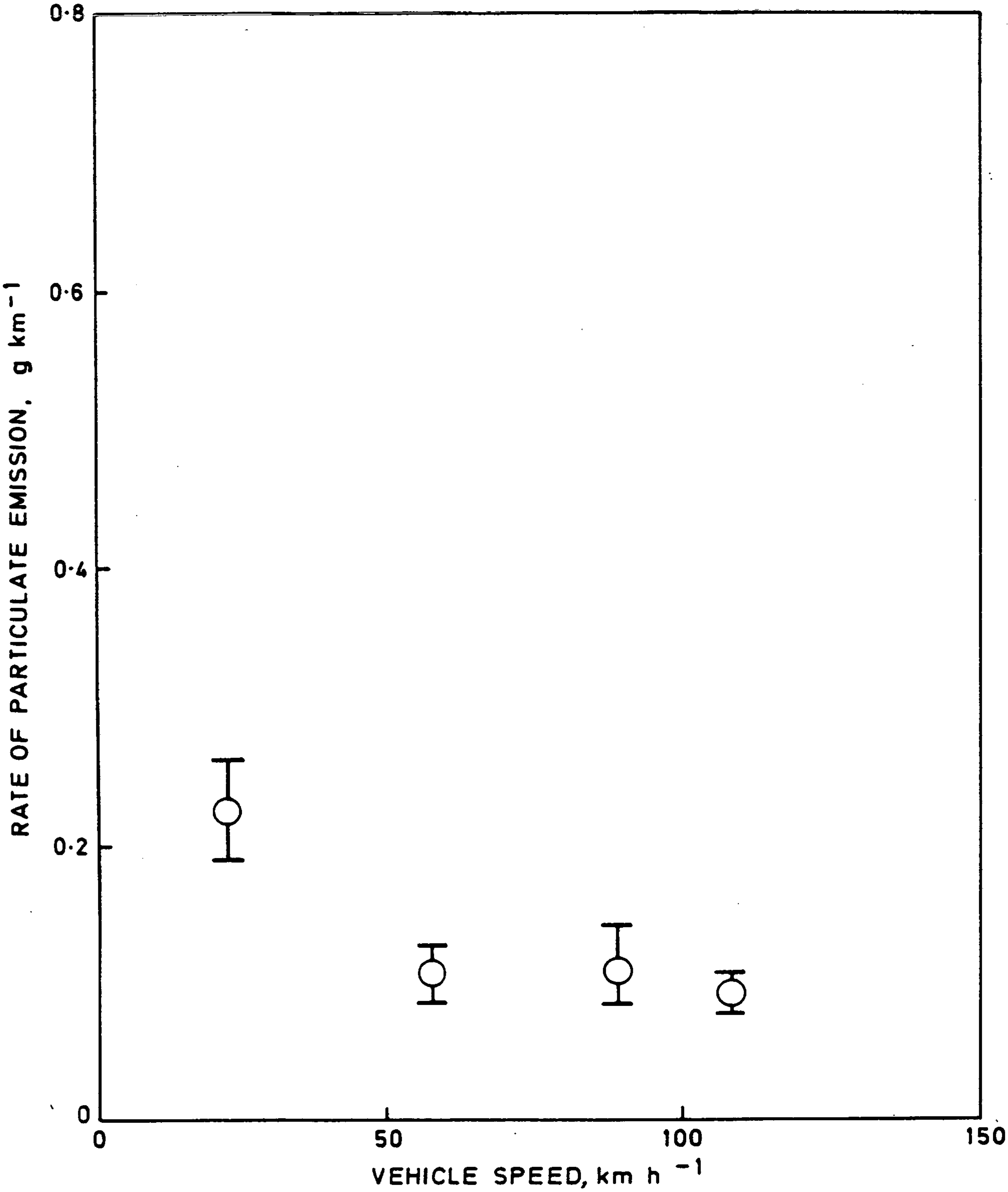

FIG. 7 VARIATION OF PARTICULATE EMISSION WITH VEHICLE SPEED. VEHICLE C

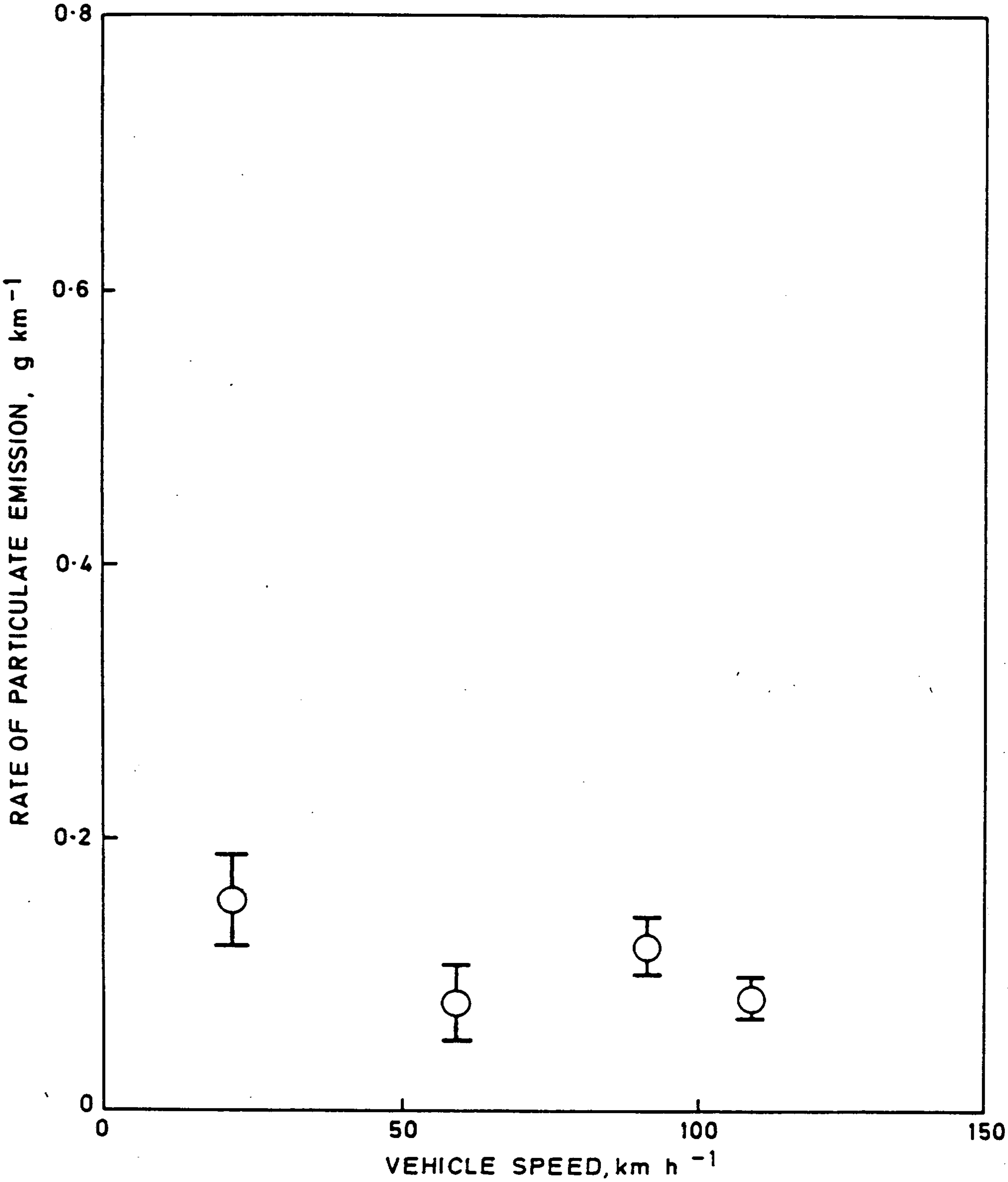

FIG. 8 VARIATION OF PARTICULATE EMISSION WITH VEHICLE SPEED. VEHICLE D

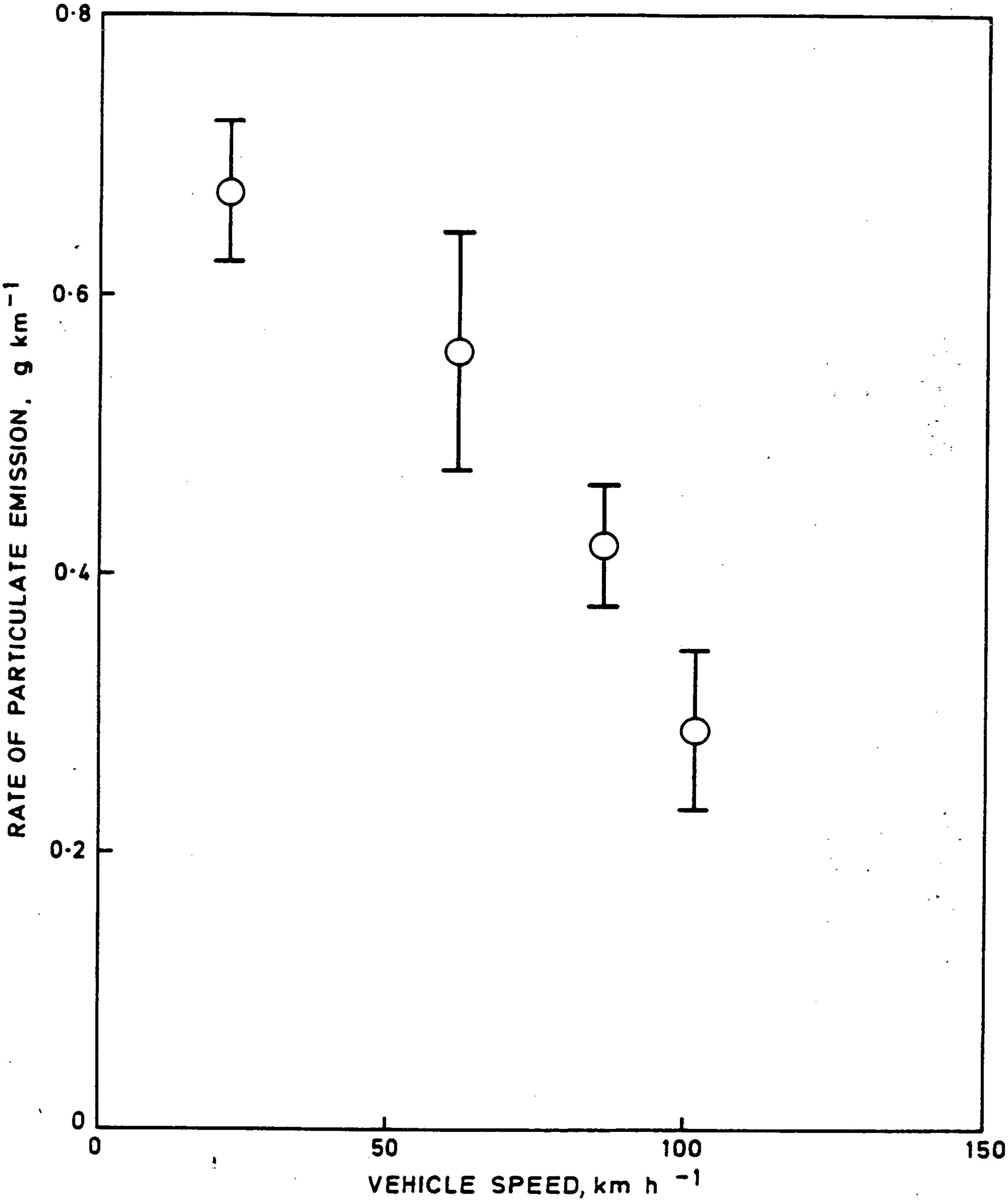

FIG. 9 VARIATION OF PARTICULATE EMISSION WITH VEHICLE SPEED.
VEHICLE E

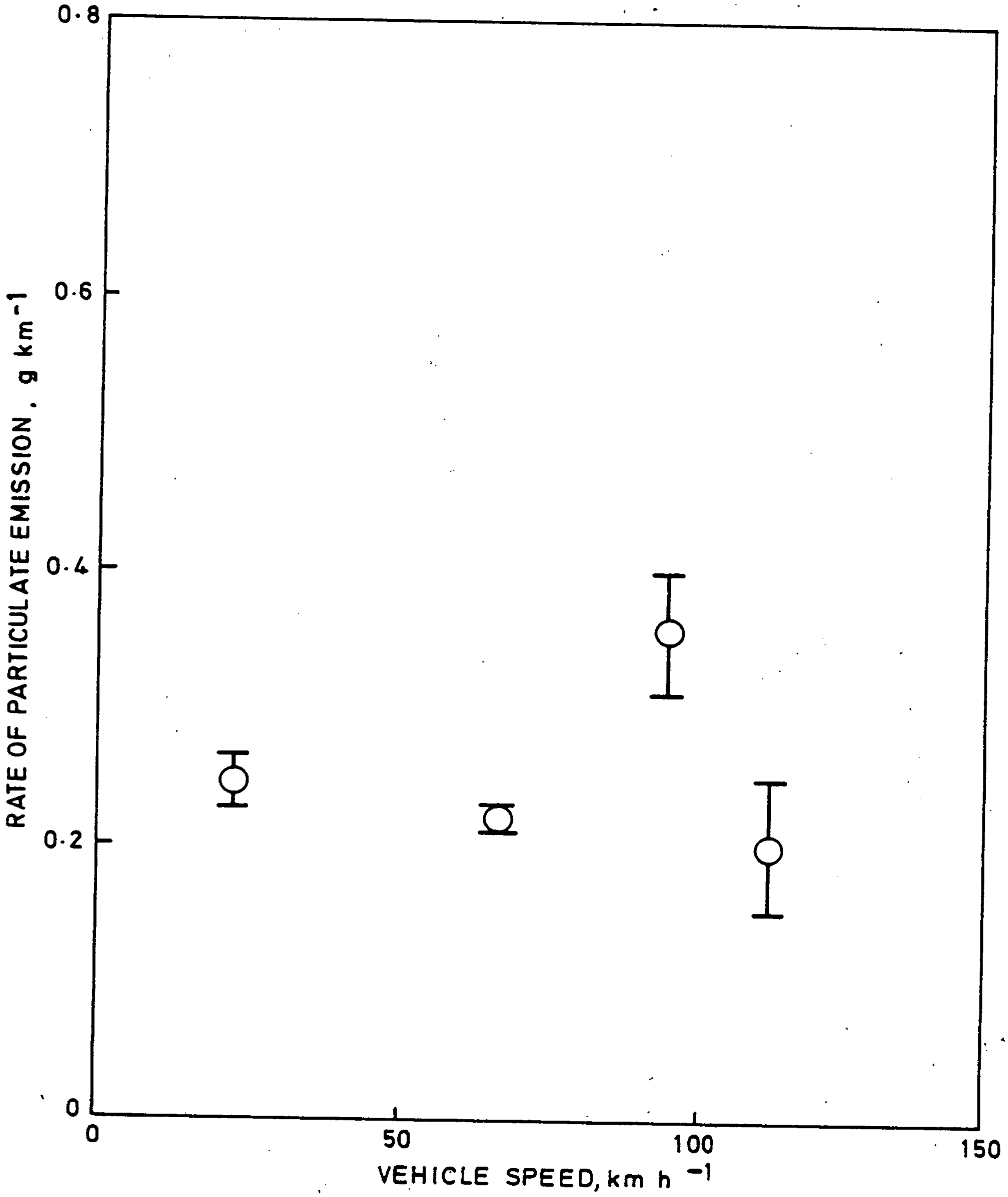

FIG.10 VARIATION OF PARTICULATE EMISSION WITH VEHICLE SPEED. VEHICLE F

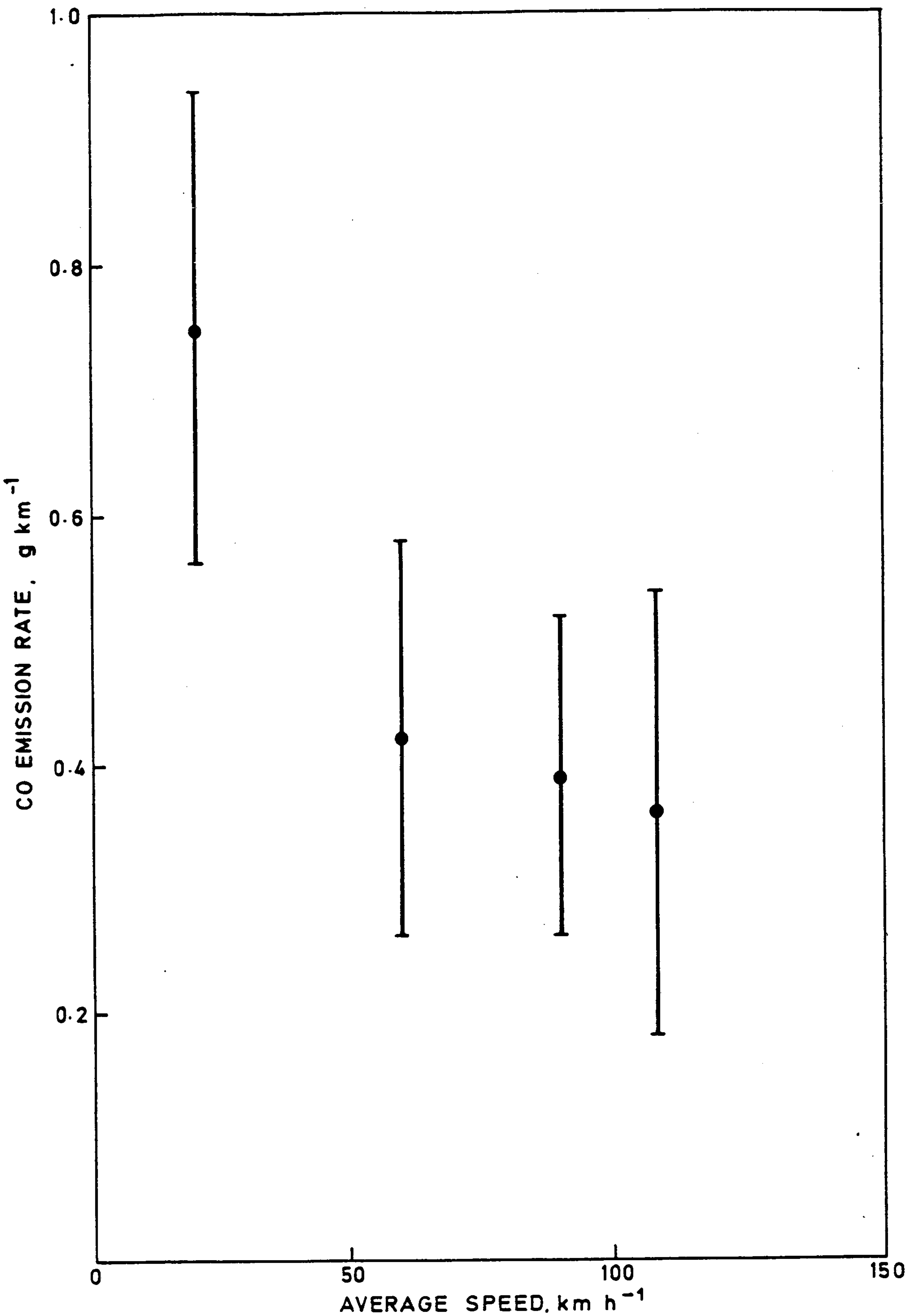

FIG.11 VARIATION OF MEAN CO EMISSIONS WITH AVERAGE SPEED ON THE ROAD. VEHICLES A, B, C, D, E AND F

17703

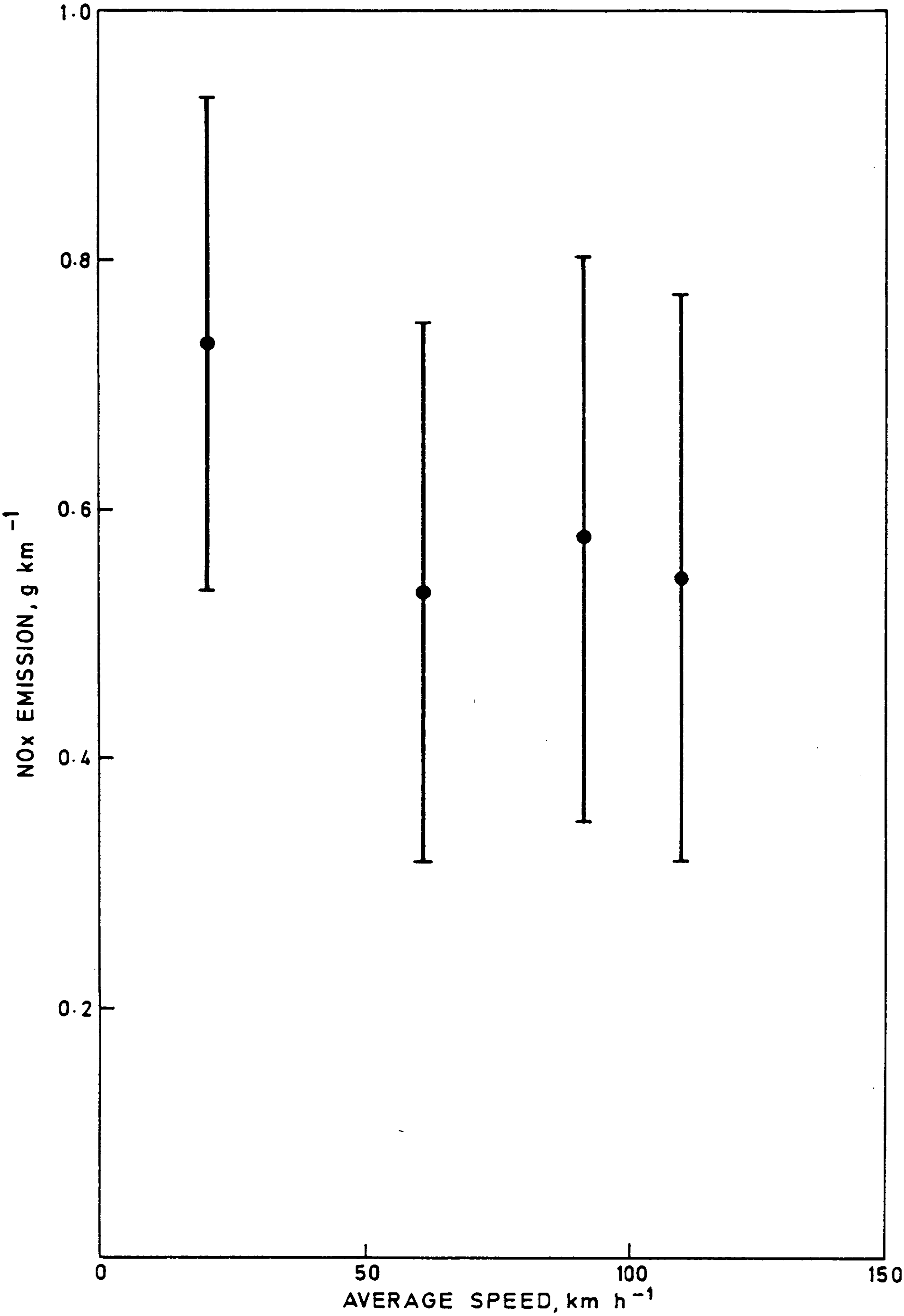

FIG.12 VARIATION OF MEAN NOx EMISSIONS WITH AVERAGE SPEED ON THE ROAD. VEHICLES A,B,C,D,E AND F

17704

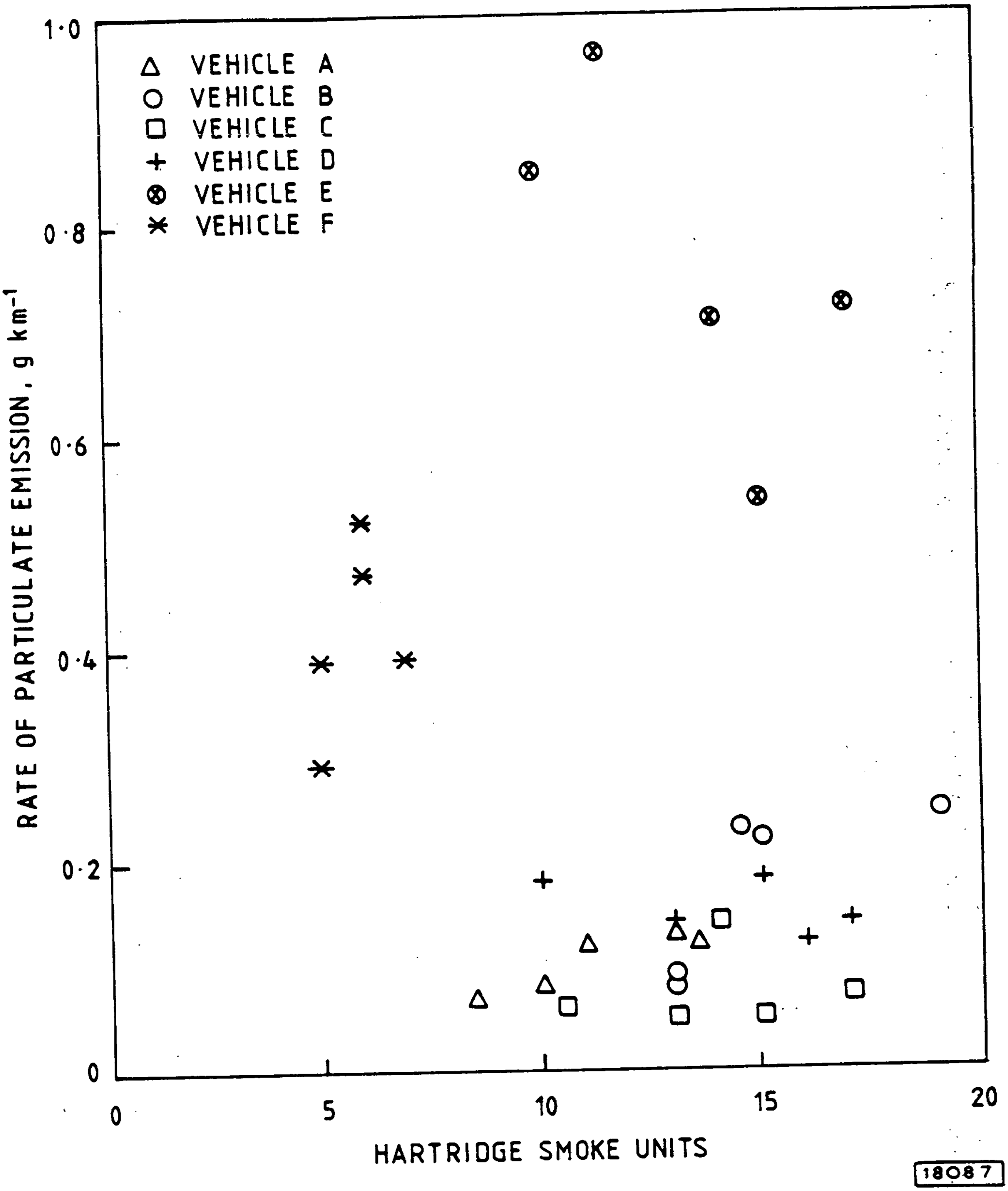

FIG. 13 RELATIONSHIP OF PARTICULATE EMISSION RATE TO 'SMOKE' READINGS

APPENDIX A
to WSL Report
CR 28 (AP)

ROAD TEST ROUTES

A Rural Route

The rural route comprised a journey from Stevenage to Hitchin. The trip length was ~11 km of which ~5 km was two lane motorway. Traffic management systems on route included five roundabouts, one set of signals and a 30 mph zone through a village. The maximum speed was about 80 km h^{-1} on the motorway and 'A' class trunk road sections.

B Urban Test Route

The urban test route of 5.46 km around Hitchin is considered representative of a typical market town and all urban drives were carried out on market day. Traffic management systems employed included roundabouts, signals, pelican and zebra crossings. Average speed of drives varied typically from 15-25 km h^{-1} according to traffic conditions.

A map of the test route is given in Fig. A1.

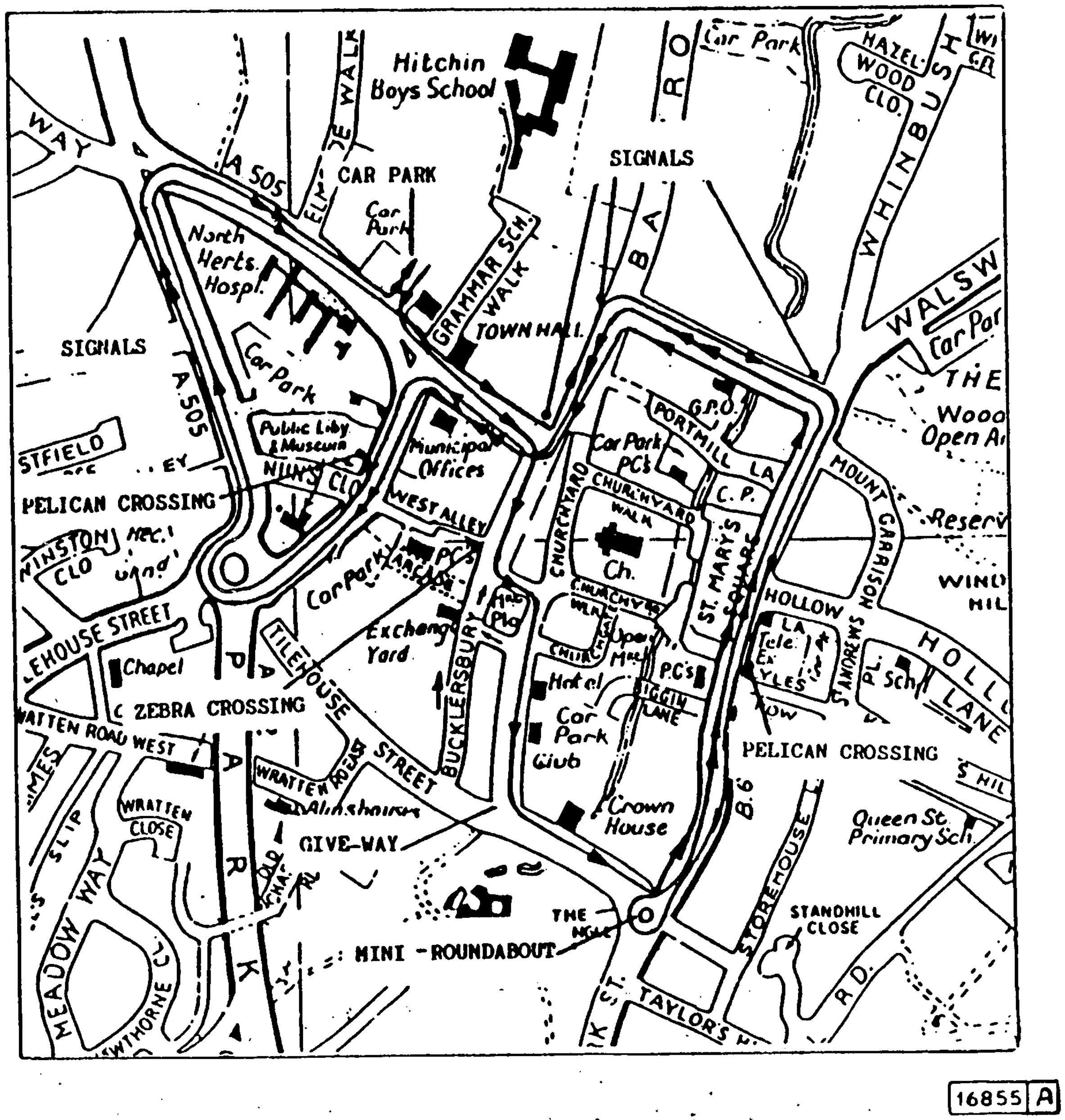

FIG. A1 HITCHIN ROUTE