SAE TECHNICAL PAPER SERIES

2003-01-0375

Demonstration of the Benefits of DPF/FBC Systems on London Black Cabs

P. Richards and B. Terry
Associated Octel Company Limited

D. Pye
ArvinMeritor Air and Emissions Technologies

Reprinted From: Diesel Exhaust Emissions Control
(SP-1754 / SP-1754CD)

2003 SAE World Congress
Detroit, Michigan
March 3-6, 2003

SAE International™

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-5760 Web: www.sae.org

For permission and licensing requests contact:

SAE Permissions
400 Commonwealth Drive
Warrendale, PA 15096-0001-USA
Email: permissions@sae.org
Fax: 724-772-4028
Tel: 724-772-4891

For multiple print copies contact:

SAE Customer Service
Tel: 877-606-7323 (inside USA and Canada)
Tel: 724-776-4970 (outside USA)
Fax: 724-776-1615
Email: CustomerService@sae.org

ISSN 0148-7191

Printed in USA

2003-01-0375

Demonstration of the Benefits of DPF/FBC Systems on London Black Cabs

P. Richards and B. Terry
Associated Octel Company Limited

D. Pye
ArvinMeritor Air and Emissions Technologies

ABSTRACT

Future emissions limits are pushing vehicle manufacturers towards the fitting of Diesel Particulate Filters (DPFs) as original equipment. However due to the replacement rate of the vehicle fleet, there is a delay before the full benefit of these measures are fully realised. To overcome this problem, in areas with a particular problem such as heavily congested city centres, retrospective legislation has been, and may be introduced. Legislation mandating the retrofitting of DPFs obviously has an immediate effect on particulate emissions. In some countries including the UK there are also fiscal incentives to fit DPFs.

Due to its duty cycle the London taxi or Black Cab is one of the more challenging areas of application for the DPF. Previous work has shown that the use of a fuel borne catalyst (FBC) can extend the operating range of DPF systems providing the possibility of a viable system for such applications. To assess the benefits of a DPF/FBC system and to demonstrate its viability on London Black Cabs a programme was undertaken using four vehicles representative of the older, "dirtier" vehicles in service. Four cars were fitted with a DPF, an on-board dosing system to meter the FBC into the fuel and a data logger to monitor the DPF performance. Emissions measurements were taken before and after fitting the DPF. The cars were then run on the road conducting normal taxi duties. After approximately 20000 km the cars were brought back for a further set of emissions measurements to be performed with the DPF fitted and again with the DPF removed.

This paper summarises two earlier papers detailing the regulated and non-regulated emissions benefits at the start of the programme and then goes on to present data from the in-service performance of the systems.

INTRODUCTION

It has been claimed (1) that "Polluted air damages health and quality of life, particularly affecting the most vulnerable in society - the very young and the old. Up to twenty four thousand people die prematurely in Britain each year from the effects of air pollution. The week-long period of high pollution in December 1991 is estimated to have caused 160 premature deaths in London."

A report prepared for the World Health Organization (WHO) considering three European countries put a price on pollution. It was estimated that the road traffic related health costs were between €310 per capita and €370 per capita (2).

Two of the air pollutants causing the most concern are particulate matter (PM), particularly PM with a diameter of less than ten micro meters (PM_{10}) and the oxides of nitrogen (NO_X) with interest now being focused particularly on Nitrogen Dioxide (NO_2).

Epidemiological studies have demonstrated a correlation between health effects and increases in airborne particulate levels. The very fine particles penetrate deeper into the lung and are thought to contribute to respiratory and cardiovascular disease. Studies have also shown particle bound organic compound, particularly Polycyclic Aromatic Hydrocarbons (PAH) to be a major source of health hazard (3).

A very effective way of reducing the particulate emissions from diesel vehicles is to fit diesel particulate filters (DPFs). Since 1998 a heavy-duty engine manufacturer has been offering engines equipped with a DPF as a factory fitted option (4). The DPF system employs a fuel borne catalyst (FBC) to ensure regeneration of the DPF. In 2000 a passenger car manufacturer began to offer a passenger car complete with DPF (5), again relying on an FBC for regeneration. Other DPF systems for heavy-duty engine application rely on the NO_2 produced by a Pt based oxidation catalyst to oxidise the trapped soot (6).

DPF systems also lend themselves to retrofit application, whether FBC based or relying on precious metals. There have been numerous demonstrations of the retrofitting of DPFs to larger vehicles (7-9). Transport for London has also embarked on a retrofit programme for the London Bus Network Fleet. However, the limitations of the systems being fitted to buses means that they are not suitable for use on the taxi fleet. Other studies have however shown that DPF/FBC systems can be successfully retrofitted to passenger cars (10-12).

In the UK, the Department of the Environment, Transport and the Regions (DETR), in conjunction with Society of Motor Manufacturers and Traders (SMMT) and CONCAWE, ran a particle research programme (13). As part of this programme, the performance of different particulate emission control devices was compared. Two vehicles used in this programme were retrofitted with DPF/FBC systems, work on these two vehicles has been reported elsewhere (11-12). Particulate emission levels were shown to be exceedingly low, even for a system which had already accumulated a distance of 60,000 km. Significantly, the filter was also very effective in lowering not only the mass but both the ultra-fine particulate fraction and number of particles.

The oxides of nitrogen consist mainly of nitric oxide (NO) and nitrogen dioxide (NO_2), NO_2 being considered the major concern to health (1,14). Due to the combustion temperatures and chemical equilibrium considerations it is expected that most of the NO_X formed within the diesel engine will be in the form of NO. However it has been postulated that NO_2 can be formed in the flame zone by reaction with HO_2 and then quenched before being reduced back to NO (3). Typical values of NO_2/NO ratios of 0.1 to 0.3 have been quoted, but it is acknowledged this is very load dependent (15,16). Exhaust NO will however then readily oxidise to NO_2 in the atmosphere in the presence of ozone (1).

Efforts by engine designers to reduce NO_2 emissions have concentrated on reducing NO_X emissions. This has traditionally been achieved by the use of exhaust gas recirculation (EGR) which acts to reduce inlet charge oxygen concentrations (17) with a small additional contribution from the thermal and chemical effect of introducing carbon dioxide CO_2 (18). The use of EGR can be incorporated into new engine designs but unfortunately does not readily lend itself to retrofitting.

Unfortunately in an attempt to reduce other emissions, namely carbon monoxide (CO) and unburned hydrocarbons (HC), the use of Pt based oxidation catalysts have shifted the NO_2/NO ratios. This problem has recently been highlighted in mining applications where ventilation is poor. In an attempt to reduce PM emissions to acceptable levels, mining equipment must be fitted with DPFs. In some cases precious metal catalysts have been used to aid regeneration of the DPFs. In some cases this can lead to an increase in NO_2 emissions. Accordingly the US mine Safety and Health Administration (MSHA) have issued an Information Bulletin (19) warning of this possible problem. If such a Pt based device is fitted in the future it must be shown that it does not increase the level of NO_2 in the raw exhaust (20).

In 1999 it was calculated that road transport contributed 52.1 % and 68.5 % to the NO_X and PM_{10} emissions respectively in Greater London. These values rose to 56.6 % and 92.5 % respectively in Central London (1). It was also estimated that taxis contributed 1.0 % and 3.9 % to the NO_X and PM_{10} emissions respectively within Greater London and contributed 6.0 % and 18.0 % respectively in Central London. In 2001 values of 66 tonnes/year of NO_X and 13 tonnes/year of PM_{10} were attributed to taxis in Central London (1).

A programme of work was thus undertaken to investigate the practicalities of retrofitting London Black Cabs with DPF/FBC systems. This paper summarises two earlier papers detailing the regulated (21) and non-regulated (22) emissions benefits at the start of the programme an then goes on to present data from the in-service performance of the systems.

VEHICLE AND FILTER SELECTION

Four taxis were chosen from the older, more highly polluting section of the London taxi fleet. This covered the two different types of vehicle in use, with the bias towards the more common LTI Fairway Driver. Brief details of the vehicles are given in Table 1 below. Also included in the table below is the equivalent km reading of the taxis' odometers at the start of the programme.

Table 1. Vehicle details

Taxi #	Reg' year	Vehicle type	Engine type	Engine capacity	Trans' type	Odo' reading
1	1994	LTI	Nissan	2664 cc	Auto	120312
2	1997	MetroCab	Ford	2496 cc	Auto	159557
3	1995	LTI	Nissan	2664 cc	Auto	339726
4	1992	LTI	Nissan	2664 cc	Man'	530879

As can be seen from the table all of the vehicles had covered in excess of 120,000 km prior to the programme. All of the LTI Fairway taxis were made to the EURO I emissions specification. The later MetroCab was made to EURO II limits and was equipped with a simple manifold vacuum actuated EGR system. All four taxis were to be fitted with silicon-carbide (SiC), wall-flow, honeycomb construction DPFs. As this was a retrofit application and space is at a premium in passenger car design, the size of the DPFs was a compromise between the desired DPF size and the space available to locate the DPF.

For the three LTI Fairway taxis a 14.4 cm x 20.3 cm (5.66" X 8") DPF was selected. This gave 3.3 litres of DPF volume for 2.7 litres of engine swept volume. The automatic transmission vehicles had filters positioned outboard of the left hand chassis rail behind the front wheel. This is shown in Figure 1 below.

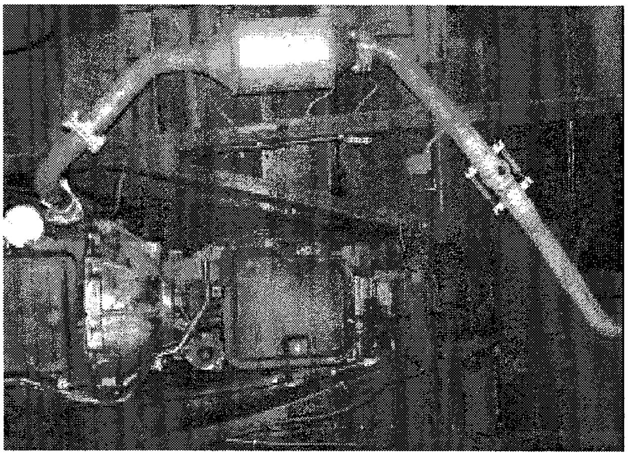

Figure 1 DPF installation on LTI Fairway (automatic)

The manual transmission vehicle had the filter positioned alongside the gearbox, inside the chassis rail. These positions were chosen so as to package the filters as close as possible to the engine. In the case of the automatic transmission LTI the distance from the exhaust manifold flange to the DPF inlet face was about 81 cm. For the manual transmission LTI this was reduced to 50 cm as shown in Figure 2 below.

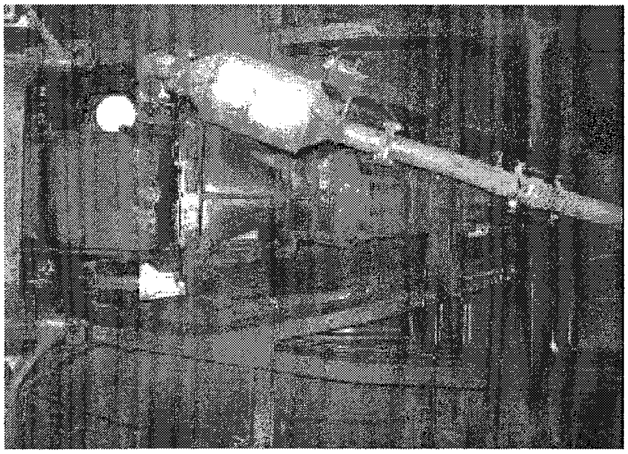

Figure 2 DPF installation on LTI Fairway (manual)

Installation of the DPF on the MetroCab was more problematic. The MetroCab has a reinforced plastic body structure, the chassis construction is more comprehensive than that of the conventionally bodied LTI Fairway. The physical geometry of the MetroCab chassis dictated that if a 14.4 cm x 20.3 cm (5.66" X 8") DPF was used it would have to be mounted slightly upstream of the first silencer box. With this arrangement the distance from the exhaust manifold flange to the inlet face of the DPF would be 230 cm.

The alternative was to use an 11.8 cm x 20.3 cm (4.66" X 8") DPF mounted slightly further forward between the chassis members as shown in Figure 3. Even with this arrangement the distance from the exhaust manifold flange to the inlet face of the DPF was 140 cm. This choice of DPF gave a filter volume of 2.2 litres for an engine swept volume of 2.5 litres.

Each DPF was fitted with a 'K' type thermocouple placed in the inlet and outlet cones. The pressure was also measured before and after each DPF. The pressure tappings and thermocouple unions are just visible in Figure 3. The information from these transducers was then recorded using a Grant 1000 series Squirrel data logger.

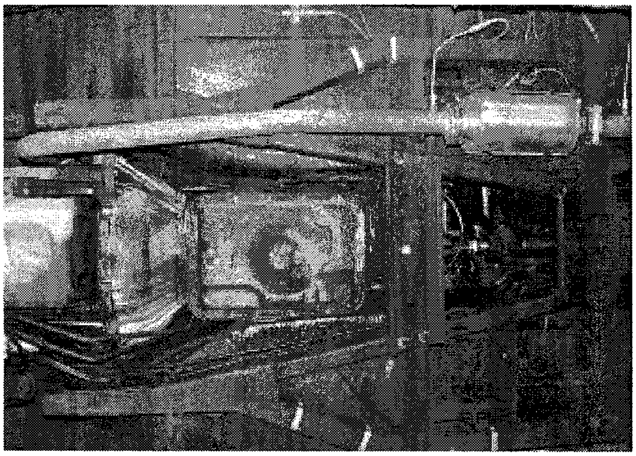

Figure 3 DPF installation on MetroCab

EMISSIONS PERFORMANCE

The MetroCab was fitted with a simple manifold vacuum actuated EGR system. As a result, any increase in exhaust back pressure would increase the EGR flow rate which would increase the soot emissions rate. This in turn would increase the back pressure still further as it increased the soot loading within the DPF. This vicious circle would result in a very rapid blocking of the DPF. To compensate for this the rate of EGR was reduced by restricting the EGR pipe. This was achieved by simply replacing the EGR pipe to manifold gasket with another gasket having a smaller orifice. The size of this orifice was then adjusted to try and match the NO_X emissions of the standard vehicle.

Regulated emissions testing was performed at Millbrook Proving Ground Limited, an independent testing facility, to the EURO III procedure. Further details of the emissions testing are given in the earlier paper (21). Additionally, NO_X speciation was performed by on-line measurement using a Fourier Transform Infra Red (FTIR) analyzer, and particle size data was obtained using an Electrical Low Pressure Impactor (ELPI) device. Further details are available in reference (22).

The taxis were tested in triplicate prior to fitting the DPF and again in triplicate once the DPF was fitted. The data from these three tests were averaged to produce an overall result. The regulated emissions results are summarised in Table 2.

Table 2. Regulated emissions results

Taxi	DPF	Emissions				Fuel Consumption
		CO (g/km)	HC (g/km)	NO_X (g/km)	PM (g/km)	(l/100km)
1	No	1.197	0.024	1.435	0.247	10.3
1	Yes	1.502	0.036	1.297	0.004	9.6
Reduction (%)		-25.5	-46.6	9.6	98.5	6.8
2	No	1.121	0.110	1.365	0.148	8.9
2	Yes	0.676	0.085	1.441	0.009	9.3
Reduction (%)		39.7	22.7	-5.6	93.9	-4.5
3	No	0.304	0.023	1.460	0.076	9.8
3	Yes	0.491	0.023	1.375	0.006	9.9
Reduction (%)		-61.2	1.4	5.8	92.5	-0.7
4	No	0.727	0.182	1.297	0.144	8.5
4	Yes	0.781	0.200	1.273	0.029	8.8
Reduction (%)		-7.4	-9.9	1.9	79.8	-3.4

Comparing the data obtained with and without the DPF gives the results as plotted in Figure 4. Although Taxi # 3 showed a large negative reduction in CO emissions it should be noted that this car produced low levels of CO in its standard form, and even with the increase due to fitting the DPF, the CO emissions from this car were still below the EURO III limits. Further details of the regulated emissions results are given in reference (21).

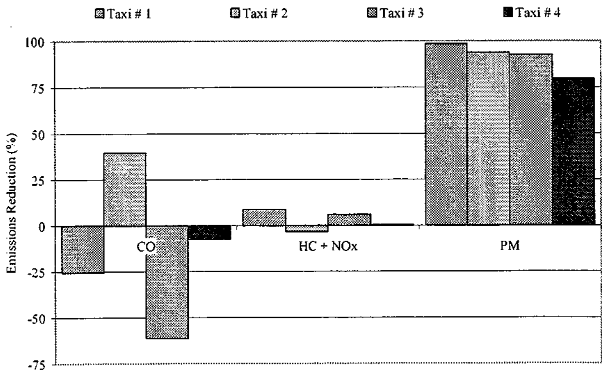

Figure 4 Regulated emissions summary

Fitting the DPF/FBC system did not significantly change the combined HC + NO_X emissions. There was a slight reduction in the HC + NO_X emissions on all the EURO I specification taxis. There was a slight increase in the NO_X emissions on the EURO II taxi as a result of modifications to the EGR system.

The emissions of major interest were obviously the PM emissions. As can be seen from Figure 4 the regulated PM emissions were significantly reduced on all four taxis. The PM reduction varied from 80 % to 98 %, the average reduction being 91 %. If this level of reduction could be achieved across the entire London taxi fleet, then the 13 tonnes/year attributed to taxis in Central London would be reduced by almost 12 tonnes/year.

The lowest reduction in PM emissions was observed on Taxi # 4. This car was also the highest emitter of HC, so it is likely that a large portion of the recorded PM is SOF and this has had a negative impact on the PM reduction. This supposition is supported by the ELPI measurements which show particle number concentration reductions of over 90 % for this taxi. The particle concentration reductions for all the taxis are presented in Table 3 below.

Table 3 Particulate concentration reduction

	Size µm (D50%)	Taxi # 1	Taxi # 2	Taxi # 3	Taxi # 4
Stage 1	0.030	98.61	99.92	98.54	92.08
Stage 2	0.060	99.53	>99.99	99.11	99.87
Stage 3	0.105	99.65	>99.99	99.71	99.74
Stage 4	0.169	99.58	>99.99	99.49	99.51
Stage 5	0.259	99.52	>99.99	99.87	96.80
Stage 6	0.399	99.72	>99.99	99.79	92.82
Stage 7	0.647	99.73	>99.99	99.97	94.71
Stage 8	1.010	99.75	99.99	99.72	98.05
Stage 9	1.630	98.77	99.99	99.61	99.92
Stage 10	2.490	99.78	99.99	99.79	98.99
Stage 11	4.030	99.82	>99.99	99.92	98.88
Stage 12	6.690	99.71	>99.99	99.80	98.98

Another major area of interest during the study was how the use of the DPF/FBC system affected the NO_X emissions and in particular NO_2 emissions. Figure 5 summarises the results for NO_X and NO_2 emissions. The NO_X emissions were reduced by an average of 3 %; this would still equate to a reduction of 2 tonnes/year if applied to the entire London taxi fleet.

It is clear from this figure that there is a significant reduction in the NO_2 emissions from the use of the DPF/FBC system. Further discussion of the NO_2 results can be found in reference (22).

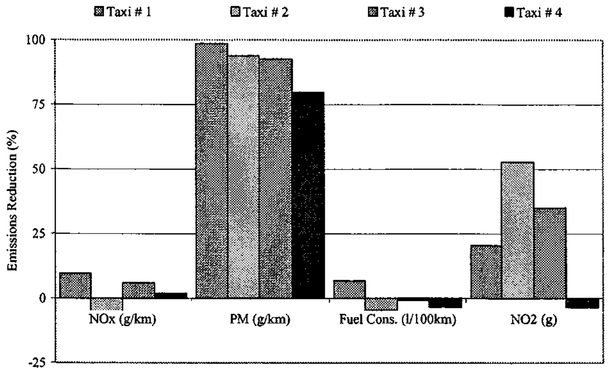

Figure 5 NO_X, PM, fuel consumption and NO_2 emissions summary

Figure 5 also shows the effect of the DPF/FBC system on the fuel consumption as measured by carbon balance. Differences in fuel consumption were small, the largest adverse effect on fuel consumption was the 4.5 % observed on Taxi #2 which was fitted with what was in effect an undersized filter. It was also interesting to note that the results on the two automatic transmission LTIs were an improvement of 6.8 % on Taxi # 1 and a deterioration of 0.7 % on Taxi # 3. These results could be taken as an indication of the reproducibility of the whole process.

REGENERATION PERFORMANCE

Whilst a significant reduction in the PM emissions is the reason for fitting the DPF/FBC system, this affect of the DPF is relatively well accepted. The major goal of this programme was thus to demonstrate that the DPF/FBC system would function on this demanding application.

From the logged data it was possible to compute the temperature histories at the DPF inlet, for the different taxis. Figure 6 shows the fraction of the vehicle running time spent above a given temperature.

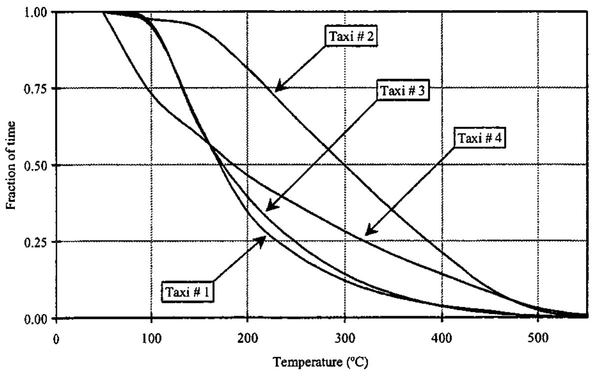

Figure 6 Temperature distributions

From the above figure it is clear that the temperature profiles of the individual taxis were significantly different. Taxi # 4 spent only 73 % of its time above 100°C whereas Taxi # 2 spent 98 % of its time above 100°C. Taxi # 1 and Taxi # 3 produced a very similar profile. Some indication as to the relative contribution to these differences of driving pattern and vehicle characteristics is obtained by looking at the temperature distributions over a known driving cycle.

The emissions drive cycle is the only readily available cycle for this comparison. Figure 7 shows the temperature distributions during the emissions test cycle for Taxi # 1 and Taxi # 2. From this figure it is clear that over the same drive cycle Taxi # 1 and Taxi # 2 produce very similar profiles although Taxi # 2 tends to run 10°C hotter than Taxi # 1. This is despite the fact that the DPF inlet face, on Taxi # 2, is about 60 cm further from the exhaust manifold than on Taxi # 1. The majority of the differences in the temperature distribution profiles illustrated in Figure 6 are therefore thought to be due to the differences in driving patterns.

During an emissions test cycle the idle DPF inlet temperature is in the range of 150°C to 160°C, thus the time spent below this temperature is indicative of the time spent "warming-up", or the number of cold starts. For Taxi # 2 this is obviously low at around 5 % of the time, whilst for the other three taxis this is higher at between 37 % and 41 % of the time. This would indicate that Taxi # 2 is performing longer trips or has shorter cool-down periods between trips.

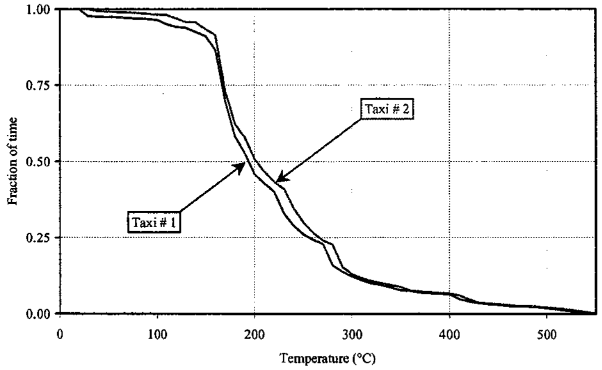

Figure 7 Temperature distribution during emissions test cycle

From the temperature histories it would be expected that Taxi # 1 and Taxi # 3 would present the biggest problem in terms of DPF regeneration. Both these taxis spent less than 15 % of their time with a DPF inlet temperature above 300°C and less than 4 % of their time with a DPF inlet temperature in excess of 400°C, however both DPFs regenerated regularly.

The exhaust back pressure histories for these two taxis over the first 2000 km of operation are presented in Figure 8. The data presented in Figure 8 is a moving average of the normalised exhaust back pressure. The equation used to normalise the back pressure was: -

$$P_{norm} = (P * N_{idle}) / (P_{idle} * N)$$

Where P is the measured pre-DPF pressure, P_{idle} is the value of P at idle with a clean DPF and N is the measured engine speed, N_{idle} is the engine idle speed.

From Figure 8 it is clear that neither DPF is regenerating on a continuous basis and soot is gradually accumulating in the DPF before being burned-out at intervals. The on-board FBC dosing system was different on these two taxis. Taxi #1 was equipped with a commercial batch dosing system which proved to be ill-adjusted to the taxi application. An alternative dosing system was thus developed and fitted to the other taxis. The alternative dosing system is more fully described elsewhere (23).

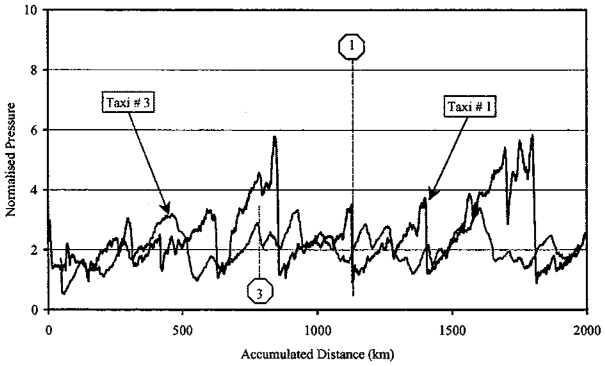

Figure 8 Normalised back pressure for Taxi # 1 and # 3

This difference in dosing system may account for the difference in regeneration characteristics of these two similar vehicles. The normalised exhaust pressure increased to higher levels on Taxi #1 indicating that a greater soot loading was present when a burn-off occurred.

Figure 9 below indicates the regeneration event that occurred on Taxi #1 at the point labeled 1 in Figure 8.

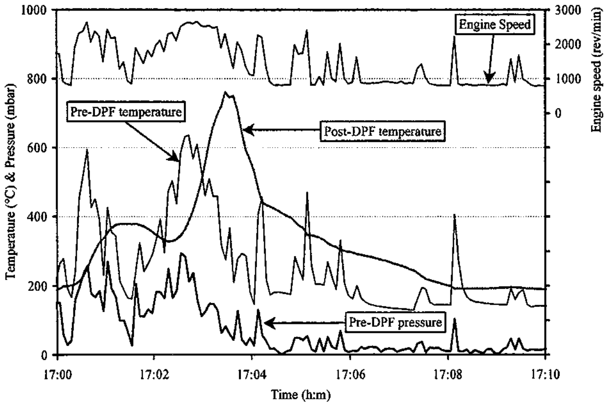

Figure 9 Regeneration on Taxi # 1

It is clear from this figure that the regeneration has been triggered by a short excursion to a very high temperature. The DPF inlet temperature has exceeded 400°C for about a minute. This was enough to initiate the regeneration and the presence of the combustion products of the FBC enabled the regeneration to progress to completion. This is indicated by the fact that the normalised exhaust pressure falls back to approximately unity.

Due to the very transient nature of the driving it is difficult to say where exactly the regeneration begins and ends. However it is fairly certain that the burn-out is complete by 17:08 suggesting that the burn time is no more than 5 minutes despite the DPF inlet temperature falling to below 200°C for most of this time.

Figure 10 shows a less complete burn-out at a far lower temperature from Taxi # 3. This data corresponds to the point labeled 3 in Figure 8. Here the regeneration event is even less well defined as indicated by both the lack of a clear exotherm in Figure 10 and the time for the normalised pressure to fall as shown in Figure 8.

The main point of interest here is that there has been some degree of regeneration at low temperature during a very short journey. Figure 10 shows the complete journey covering 5 km. As this regeneration event occurs within such a short time of engine start, and where the average DPF inlet temperature is about 170°C, it is highly likely that there was a far higher than normal amount of unburned hydrocarbons adsorbed on the trapped particulate. The presence of HC and FBC products have previously been connected with low temperature regeneration events (10, 24).

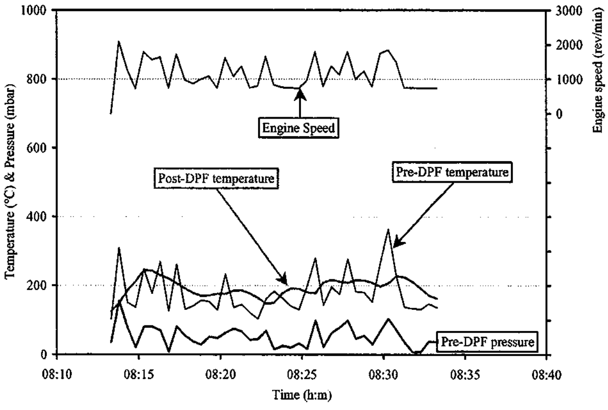

Figure 10 Regeneration on Taxi # 3

Figure 11 shows a comparison of the normalised exhaust back pressure for Tax1 # 2 and Taxi # 3. Both vehicles were operating with similar FBC dosing systems. As shown in Figure 6, Taxi # 2 spent far more of its time operating with a DPF inlet temperature in the range 300°C to 450°C. It must also be remembered that the DPF on Taxi # 2 was about two thirds the volume of that on Taxi # 3, this would result in a lower thermal mass for the DPF on Taxi # 2. Due to the packaging constraints it was also considered necessary to fit a heat shield to the upper half of the DPF on Taxi # 2 in order to protect the vehicle underside. All these factors would combine to make it far more likely that the critical conditions for DPF regeneration would be reached in Taxi # 2. This is confirmed by the relatively small variation in normalised pressure as shown in Figure 11.

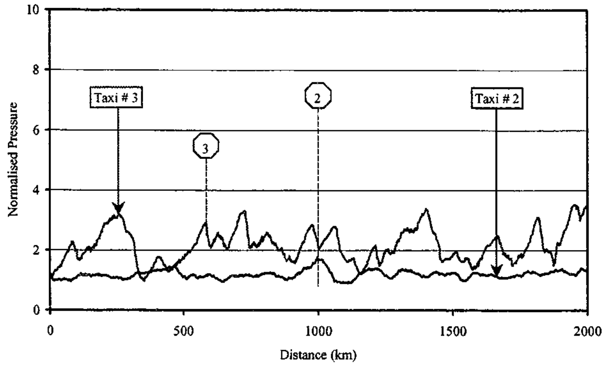

Figure 11 Back pressure for Taxi # 2 and Taxi # 3

A regeneration on Taxi # 2 is illustrated in more detail in Figure 12. This chart shows the regeneration event highlighted as point 2 in Figure 11. The DPF inlet temperature has exceeded 500°C for over a minute, however the post DPF temperature is greater than the inlet after about half of this time. It is also interesting to note how the exotherm increases as the engine speed, pre-DPF temperature and pressure fall. This is characteristic of the falling gas flow and hence reduced heat dissipation.

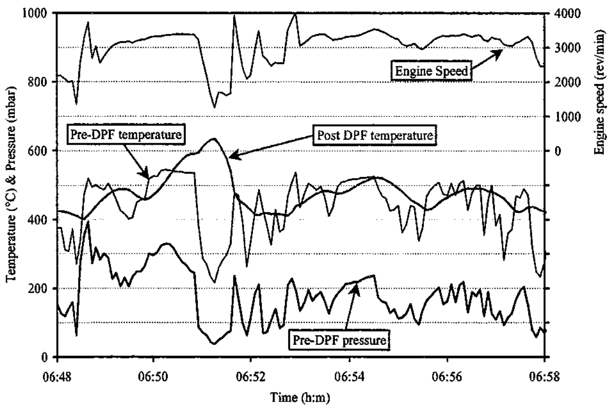

Figure 12 Regeneration on Taxi # 2

CONCLUSIONS

Four taxis, built to comply with previous emissions limits, were taken from service and retrofitted with DPF/FBC systems. One of the taxis was equipped with EGR and required an adjustment to the EGR system to maintain EGR levels. All four taxis showed reductions in regulated PM emissions of greater than 79% as a result of using the DPF/FBC systems. However if the average reduction of 91% is taken then based on year 2001 figures this would result in a 12 tonnes/year reduction in PM emissions in Central London.

Particle size measurements showed that fitting the DPF/FBC system reduced the number of particles by between 92.1 % and over 99.99 %. These reductions also applied to the sub 100 nm particles.

The effect of the DPF/FBC system on the other regulated emissions varied from taxi to taxi. The taxi with EGR showed a significant reduction in CO emissions and a small increase in NO_X with the DPF/FBC system whilst the other three taxis exhibited an increase in CO emissions and a small decrease in NO_X. The average effect on NO_X emissions was a reduction of 3% which on year 2001 figures would still yield a 2 tonnes/year reduction in NO_X emissions in Central London.

Although the benefit of fitting the DPF/FBC system was only a small reduction in NO_X the effect on NO_2 was generally much greater.

The effect on HC emissions was again varied, two taxis exhibited a reduction whilst the other two exhibited an increase. The overall result being that only the taxi with EGR showed an increase in the combined HC + NO_X emissions and this could probably be adjusted with further work.

The effect on fuel consumption was again varied, ranging from a decrease of 6.8% to an increase of 4.5%.

In service the DPF/FBC system allowed regular spontaneous regeneration of the DPF despite a temperature profile that meant that three of the vehicles spent less than 50% of their time with DPF inlet temperatures above 200°C. Two of these vehicles also spent less than 15% of their time with temperatures above 300°C.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to the Energy Saving Trust for sponsoring this programme of work. The authors are also grateful to Bob Larbey for managing the project and to Neil Balderson, Stanley Robertson and Brian Macey of Millbook Proving Ground Limited for their assistance with the emissions testing.

REFERENCES

1. "The Mayor's Draft Air Quality Strategy for Public Consultation" Greater London Authority, September 2001
2. Kunzli N., Kaiser R., Medina S., Studnicka M. oberfeld G. and Horak F. "Air Pollution Attributable Cases- Technical Report on Epediiomology" Third WHO Miniserial Conference of Environment and Health. London 1999
3. Bagley S. T., Baumgard K. J., Gratz L. D., Johnson J. H. and Leddy D. G. "Characterisation of fuel and aftertreatment device effects on diesel emissions" Health Effects Institute. Research Report No 76. Sept. 1996

4. Czerwinski J., Jaussi F., Wyse M. and Mayer A. "Particulate Traps for construction Machines Properties and Field Experience" SAE 2000-01-1923
5. Salvat O., Marez P. and Belot G. "Passenger Car Serial Application of a Particulate Filter System on a Common Rail Direct Injection Diesel Engine" SAE 2000-01-0473
6. Cooper B. J. and Thoss J. E. "Role of NO in Diesel Particulate Emission Control" SAE 890404
7. Seguelong T and Fournier-Bidoz P. "Use of Diesel Particulate Filters and Cerium-Based Fuel-Borne Catalyst for Low Temperature - Low Load Applications" SAE 2001-01-0906
8. Chatterjee S., Conway R., Lanni T., Frank B., Tang S., Rosenblatt D., Bush C., Lowell D., Evans J., McLean R. and Levy S. "Performance and Durability Evaluation of Continuously Regenerating Particulate Filters on Diesel Powered Urban Buses at NY City Transport - Part II" SAE 2002-01-0430
9. LeTavec C., Uihein J., Vertin K., Chatterjee S., Hallstrom K., Wayne S., Clark N., Gautam M., Thompson G., Lyons D., Chandler K. and Coburn T "Year-Long Evaluation of Trucks and Buses Equipped with Passive Diesel Particulate Filters" SAE 2002-01-0433
10. Richards P., Vincent M. W. and Cook S. L. "Operating Experience of Diesel Vehicles Equipped With Particulate Filters and Using Fuel Additive For Regeneration." SAE 2000-01-0474
11. Vincent M. W. and Richards P. "The Long Distance Road Trial of a Combined Diesel Particulate Filter and Fuel Additive." SAE 2000-01-2849
12. Richards P., Terry B., Vincent M. W. and Chadderton J. "Combining Fuel Borne Catalyst, Catalytic Wash Coat and Diesel Particulate Filter" SAE 2001-01-0902
13. "Andersson J., Wedekind B., Wilson G., Hall D. and Stradling R. "DETR/SMMT/CONCAWE Particulate Research Programme: Effects of Particulate Traps on Particle Size, Number and Mass Emissions from Light and Heavy Duty Diesel Engines" I.Mech.E. C588/021/2000
14. "What is air polution?" King's College London http://www.erg.kcl.ac.uk/london/asp/information.asp
15. Heywood J. B. "Internal Combustion Engine Fundamentals" McGraw-Hill, New York 1998
16. Hilliard J. C. and Wheeler R. W. "Nitrogen Dioxide in Engine Exhaust" SAE 790691
17. Ladammatos N., Abdelhalim S. M., Zhao H. and Hu Z. "The Dilution Chemical and Thermal Effects of Exhaust Gas Recirculation on diesel Engine Emissions- Part 1: Effects of Reducing Inlet Charge Oxygen" SAE 961165
18. Ladammatos N., Abdelhalim S. M., Zhao H. and Hu Z. "The Dilution Chemical and Thermal Effects of Exhaust Gas Recirculation on diesel Engine Emissions- Part 2: Effects of Carbon Dioxide" SAE 961165
19. "Potential Health Hazard Caused by Platinum Based Catalyzed Diesel Particulate Matter Exhaust Filters" Mine Safety and Health Administration, Program Information Bulletin No P02-4, May 31, 2002
20. "Compliance with Diesel particulate Matter Standard in Underground Coal Mines" Mine Safety and Health Administration, Program Information Bulletin No P02-7, July 16, 2002
21. Terry B., Richards P. and Pye D. "Experience of fitting London Black Cabs with Fuel Borne Catalyst assisted Diesel Particulate Filters - Part 1 Regulated Emissions and Regeneration Performance" 2002-01-2784
22. Richards P., Terry B. and Pye D. "Experience of fitting London Black Cabs with Fuel Borne Catalyst assisted Diesel Particulate Filters - Part 2 Non-regulated emissions measurements" 2002-01-2785
23. Vincent M. W., Richards P. J. and Catterson D. J."A Novel Fuel Borne Catalyst Dosing System For Use With A Diesel Particulate Filter" 2003-01-0382
24. Kandylas I. P., Stamatelos A. M. "Modeling Catalytic Regeneration of Diesel Particulate Filters, Taking into Account Adsorbed Hydrocarbon Oxidation" Ind. Eng. Chem. Res. 1999, 38, 1866-1876

CONTACT

For further information contact

Paul Richards Tel: +44 1908 273 638
Fax: +44 1908 273 613
Email: richardsp@octel-corp.com

Barbara Terry Tel: +44 1908 273 640
Fax: +44 1908 376 033
Email: terryb@octel-corp.com

Associated Octel
Fuel Technology Centre
Watling Street
Bletchley
Milton Keynes
MK1 1EZ
England

http://www.octel-corp.com

David Pye Tel: +44 1772 851 222
Fax: +44 1772 679 528
Email: david.pye@ArvinMeritor.com

ArvinMeritor Air and Emissions Technologies
Hillock Lane
Warton
Preston
PR4 1TP
England

http://www.arvinmeritor.com