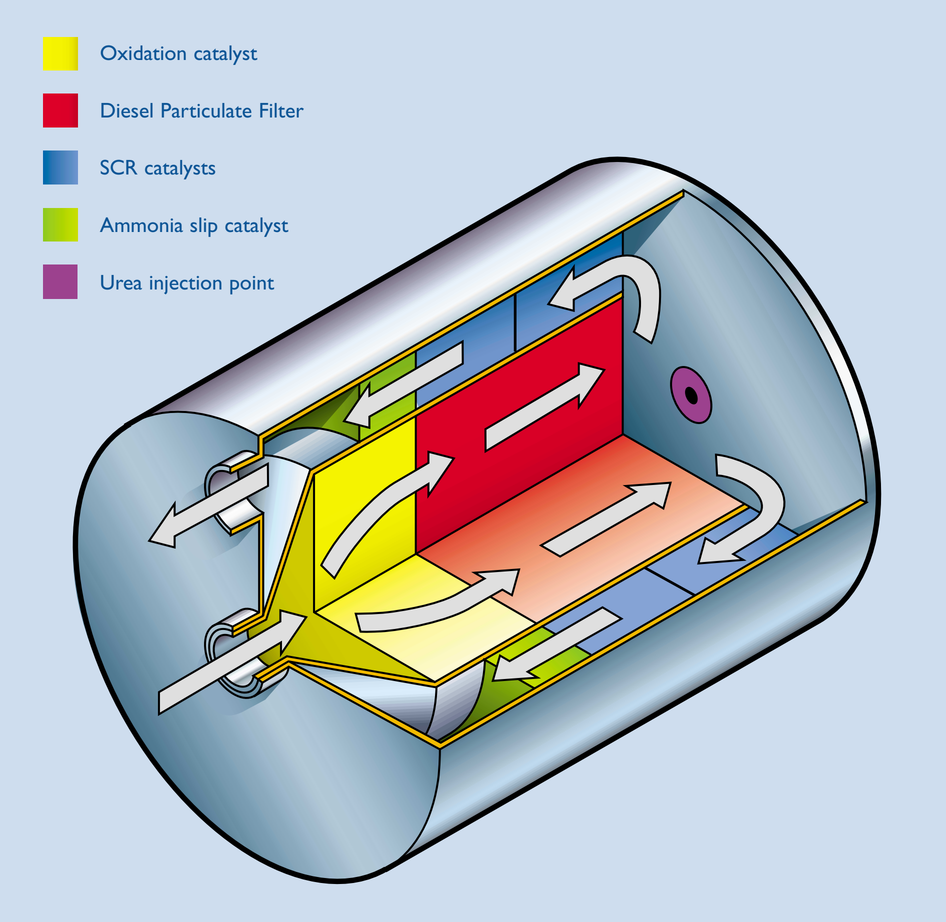
'Compact SCRT™' Schematic



The 'Compact SCRT™' Unveiled

The SAE 2003 World Congress in Detroit provided an ideal opportunity for Johnson Matthey to give an update on its innovative SCRT™ concept. As well as unveiling a new 'Compact SCRT™' design, Johnson Matthey reported on testing work confirming emissions performance and system durability.

Background

The SCRT refers to the combination of Continuously Regenerating Trap (CRT®) technology with Selective Catalytic Reduction (SCR). First presented at the SAE World Congress in March 2000, the SCRT attracted immediate attention as the first catalytic approach capable of delivering a 90% reduction of all four regulated pollutants. This marked it out as a means by which diesels could meet the toughest emissions regulations.

Among the European engine manufacturers, SCR is considered a favoured route by which trucks can achieve Euro 4 and 5 because it allows engine tuning for enhanced fuel economy by tackling the resulting increases in nitrogen oxides (NO_X). SCRT offers this same opportunity to simultaneously improve NO_X emissions and fuel economy but with the additional opportunity to retain a filter – something considered essential by the sponsors of many urban bus fleets.

In seeking to further develop the SCRT concept, Johnson Matthey catalyst scientists needed to address potential barriers to its application. These were identified as packaging constraints, durability and cost.

Compact Packaging

Initial SCRT development focused on 'linear' configurations where the CRT was followed by an in-line SCR unit. It was recognised that this approach might suit long wheel base buses, or trucks with vertical stacks, but would be unsuitable for vehicles with space constraints where a drum silencer would be preferred. The challenge was to work out how vehicles that only just had enough space for a CRT could accommodate the additional SCR unit required in an SCRT. To address this Johnson Matthey looked at a number of different designs, focusing particularly on the opportunities afforded by novel substrate configurations. This work resulted in the 'Compact SCRT' design.

The key feature of the Compact SCRT is the use of metallic annular substrates for the SCR catalysts – that is catalysts with a hole in the middle. By making the central aperture big enough to fit a diesel particulate filter (DPF), the SCR catalysts could effectively wrap around the filter, thereby increasing the width without necessarily adding to the length of the CRT-based exhaust. As with a linear SCRT configuration, the inlet to the SCRT channels the exhaust gas through the oxidation catalyst of the CRT, cutting HC and CO emissions and generating NO_2 to burn soot in the filter and boost the rate of downstream SCR reactions. The filter traps the soot, leaving an exhaust gas free from HC, CO and PM emissions, into which the urea-water solution can be injected to generate the ammonia needed for the NO_X reduction. This dosing of the urea solution takes place a comparatively short distance away from the SCR catalysts but the internal design ensures the effective mixing of urea sprays and exhaust gases, before the flow is turned 180° to enter the SCR catalysts. The final ammonia slip catalyst helps ensure that ammonia slip is negated.

Durability

The durability of the CRT has been proven through the many thousands of hours of trouble-free operation accumulated on vehicles. Furthermore, the factors influencing CRT durability, including fuel sulphur content, NO_X/PM ratio, exhaust gas temperature (duty cycle) and filter maintenance are well understood. SCR catalyst durability has been proven, in units employed to clean up the emissions of power plant. However, for vehicular applications, SCR and SCRT durability is just beginning to be demonstrated.

Annular Catalyst

> "Encouraged by the performance of the SCRT^{TM} Johnson Matthey has supplied systems to Volvo for field trials on haulage trucks in North America."

To prove SCR catalyst durability, the effects of long term operation were simulated using catalyst ageing and then emissions performance measured using engine dynamometer testing. In unison with this work, SCRT units have been field-tested in real-world operation.

The internal packaging of the SCRT holding the substrates in place is more complex than the illustration indicates, given that the structure must provide the necessary noise attenuation and strength of a conventional silencer, whilst allowing access to the filter for maintenance purposes as a modular CRT would. To demonstrate the mechanical durability of the 'Compact SCRT' units were subjected to shake testing and pressure pulse testing.

Emissions Performance

When the SCRT was first unveiled, the emissions target for HDD applications was the Euro 5 limit of 0.02 g/kWh PM and 2 g/kWh NO_x on the European Steady-state Cycle (ESC). Subsequently both the United States and Japan have applied stringent emissions legislation targeting NO_x and PM control, with the US2007 limits of 0.01 g/bhp.hr PM and 0.2 g/bhp.hr NO_x recognised as the most stringent regulations yet devised for heavy-duty diesels. Given this new target, the emissions measurement and system optimisation work focused on achieving a very high NO_x conversion efficiency.

When tested on the ESC the SCRT comfortably met the proposed Euro 5 emissions limits for all four pollutants, demonstrating an 84% NO_x conversion when employing 2 SCR catalysts and a 92% conversion with an extra SCR catalyst added. For these systems HC and CO conversions were exceptionally high at 98% and 100% respectively. The PM conversion was lower at around 70% but this reflected the inherently low PM emissions of the engine, which at 0.022 g/kWh, were almost low enough to meet Euro 5 without a filter!

In this system the ammonia slip levels measured before the slip catalyst were inside the accepted industry target of 10 to 15ppm max, which illustrates what can be achieved with an optimised injection strategy (matching urea solution injection to NO_x exhaust requirements). With a clean up catalyst added, ammonia slip was eliminated.

In contrast to ESC testing, the US Heavy-Duty Transient (HDT) test starts with the engine cold and thereby emphasises cold start emissions. Because urea only hydrolyses to ammonia in hot exhaust gas it is not possible to inject urea during the early stages of the test and consequently NO_x emissions reduction fell to just 56%. However, on a hot start US HDT test the NO_x conversion improved to reach 83%. Using weighted emissions ($^1/_7$th cold, $^6/_7$th hot), NO_x emissions reduction reached 79% with HC and CO conversions of 96% and 94% respectively.

The Next Steps

Encouraged by the performance of the SCRT, Johnson Matthey has supplied systems to Volvo for field trials on haulage trucks in North America. These trucks will accumulate high annual mileages, providing an effective guide to real-world durability.

Commenting on the compact SCRT design, Johnson Matthey's Dr Barry Cooper said "Our Compact SCRT design provides an easy-to-package emission control device capable of providing very high conversions of all four major pollutants. I am confident that the field trials on Volvo trucks will help confirm the Compact SCRT durability together with the excellent emissions performance demonstrated in our testing to-date."

A 'Compact SCRT^{TM}' and CRT packaged by Eminox

NO_x Adsorber Developments for Diesel Emissions Control

For light and heavy-duty diesels, catalytic systems can supplement the nitrogen oxides (NO_x) control offered by engine-related measures. So called NO_x Adsorber Catalysts (NAC) can offer NO_x conversion efficiencies in excess of 90% over a wide temperature window. This article summarises a Johnson Matthey technical paper presented at the SAE World Congress, which outlines improvements in NAC performance.

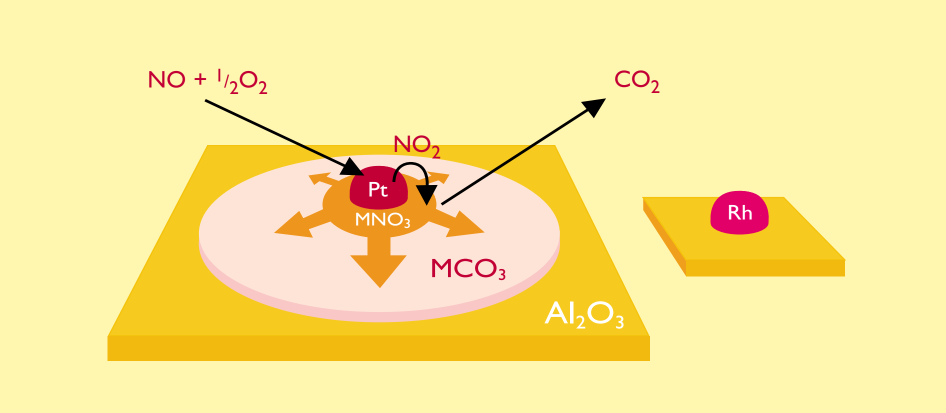
The chemical principles behind NO_x Adsorber Catalysts (NACs), also known as Lean NO_x Traps, are well documented. Under lean conditions, the NAC promotes NO_x adsorption as illustrated by reactions 1 and 2, where M is the NO_x adsorbing element, MCO_3 is the adsorber material, and MNO_3 is the stable NO_x containing compound.

(1) $NO + {}^{1}/_{2}O_2 \Rightarrow NO_2$

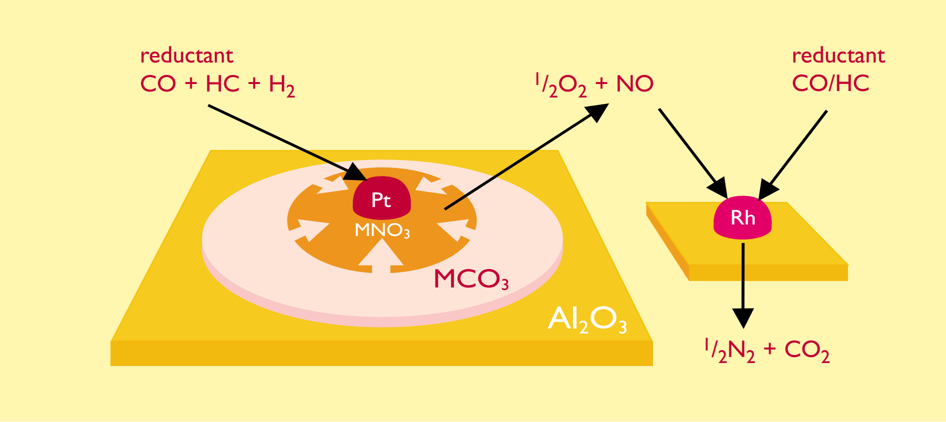
(2) $NO_2 + MCO_3 \Rightarrow MNO_3 + CO_2$

Under fuel-rich conditions, the NAC promotes decomposition of the nitrate phase to release the stored NO_x (reaction 3). The NAC then catalyses the reduction of NO_x to form N_2 (reaction 4).

Lean Conditions



Rich Conditions



(3) $MNO_3 \Rightarrow MO + {}^{1}/_{2}O_2 + NO$

(4) $NO + CO/HC \Rightarrow {}^{1}/_{2}N_2 + CO_2$

The drawback of these catalysts has been their sensitivity to fuel sulfur. NO_x adsorber materials are very efficient adsorbers of sulfur oxides, ultimately forming sulfate. Unfortunately sulfur blocks the adsorption sites and consumes adsorber by forming stable sulfate (reaction 7), thereby reducing the efficiency by which the NAC adsorbs NO_x.

(5) $MO + CO_2 \Rightarrow MCO_3$

(6) $SO_2 + {}^{1}/_{2}O_2 \Rightarrow SO_3$

(7) $SO_3 + MCO_3 \Rightarrow MSO_4 + CO_2$

Under rich conditions, the adsorbed sulfur can be desorbed but this requires a higher temperature than that required for the NO_x release. So, unless the engine operates on sulfur-free diesel, the successful application of a NAC within an emissions management system depends on the impact of temperature on the performance of the NAC, both in terms of NO_x adsorbtion efficiency and NAC durability after high temperature operation.

The NAC functions by forming chemical compounds that store the NO_x. The performance of an emissions control system incorporating a NAC is significantly influenced by the temperatures at which these compounds form and decompose. By using appropriate adsorber materials, NO_x storage can be enhanced at both low and high temperatures, helping to broaden the effective operating temperature window within which NO_x is controlled.

NAC durability

A NAC must be able to maintain its activity whilst withstanding high temperatures. This is because emissions management systems are under development for light-duty diesels that employ a NAC in conjunction with a particulate filter. The trapping function of the particulate filter must be regenerated, which involves periodically injecting fuel, either in-cylinder by engine management techniques or directly into the exhaust gas, to raise the temperature to around 600°C to burn away the soot in the filter. Likewise, when desulfating the NAC under rich conditions, the NAC can be exposed to even higher temperatures.

Thermal durability can be demonstrated for the latest NAC formulations by measuring NO_x conversion efficiency on aged samples after repeated sulfation and desulfation cycles.

Figure 1 illustrates that NAC activity does fall after the first and second sulfation and desulfation but is stable thereafter. Repeated testing confirmed the reproducibility of this effect. This stable sulfation-desulfation behaviour is important for the long-term durability of a NAC system in actual use on a vehicle.

Low and High Temperature NAC Performance

The potential application of NAC on European passenger cars requires that the NAC give good performance at exhaust gas temperatures below 250°C, reflecting urban driving. However, the exhaust gas temperatures generated by these same diesels can be significantly higher when the cars are motorway driving. Figure 2 shows NAC formulation A, which gives good low temperature performance, and a modified formulation, NAC B, which gives better high temperature performance. Formulation B's good high temperature activity makes it suitable for heavy-duty diesel applications, where high engine loads make relatively high exhaust gas temperatures a common occurrence.

NAC System Design

The first step in the NO$_x$ storage process is the oxidation of NO to NO$_2$ (reaction 1). This reaction is catalysed by platinum incorporated into the NO$_x$ Trap. Under some operating conditions this NO oxidation reaction can be inhibited and there are advantages in employing an optimised NO$_x$ oxidation catalyst (NOC) upstream of the NAC to provide additional NO$_2$, particularly at low temperatures.

Figure 3 summarises the NO$_x$ conversions obtained for NAC A with and without an upstream NOC and with the various cycle timings employed, ranging from 120 seconds lean and 2 seconds rich to 60 seconds lean and 8 seconds rich operation. The benefit of a NOC is apparent regardless of the cycle timing.

A further benefit of using a NOC in the system is seen in tailpipe HC emissions. For NAC-based systems, controlling HC emissions can be a challenge, particularly during the rich pulse where extra fuel is injected at the same time as oxygen is depleted. During the rich pulse, HC emissions were 80% lower when an upstream NOC was employed.

Low Temperature Performance Revisited

Having demonstrated improved high temperature performance with NAC B compared with NAC A, further developments led to a new C formulation which gave equivalent high temperature activity (> 280°C) to NAC B but superior low temperature activity (< 280°C) as shown in Figure 4. The very wide activity window demonstrated by NAC C will allow greater system design flexibility, and very high NO$_x$ conversions over a comprehensive range of diesel applications.

Conclusions

Commenting of the results, Johnson Matthey Technology Director Dr Martyn Twigg said "Given the NO$_x$ conversions achievable it is understandable why there is intense interest in using NO$_x$ adsorber catalyst (NAC) technology for light-duty and heavy-duty diesel applications. The key to improving NAC performance lies in the capability of the catalyst designer to widen the operating window whilst retaining activity and thermal durability. These results demonstrate very good progress is being made in this direction."

Figure 1: NAC Activity After Sulfation and Desulfation

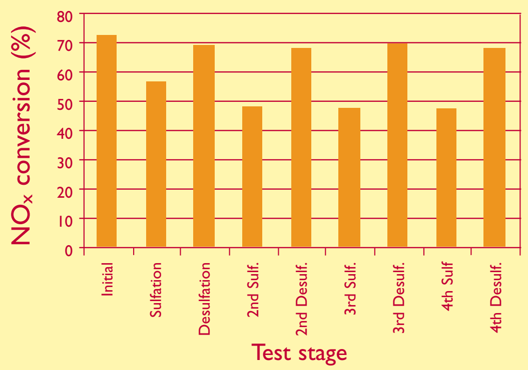


Figure 2: Activity of NAC A and B showing improved high temperature activity of NAC B

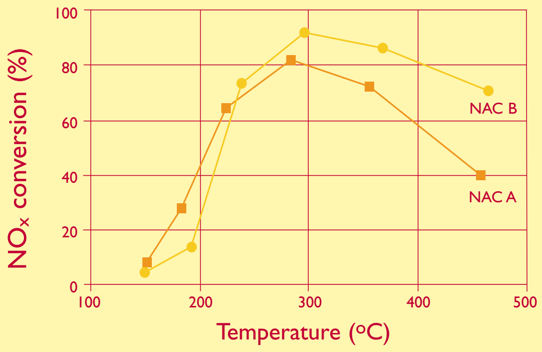


Figure 3: Effect of lean/rich cycle timings on system activity at 350°C for NAC A, with and without an upstream NOC

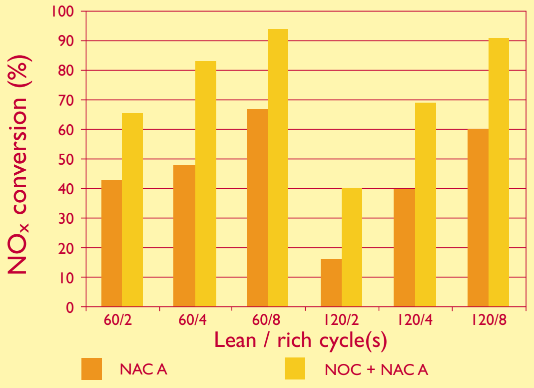
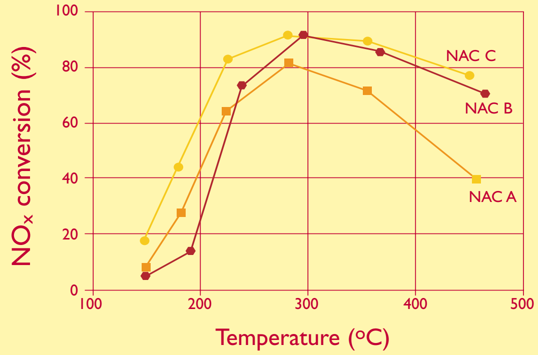
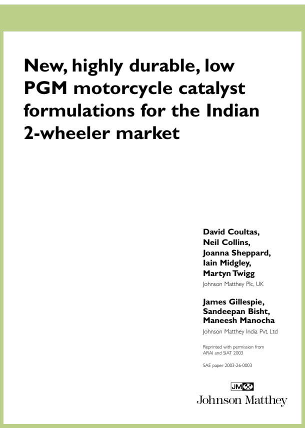


Figure 4: Comparison of the NO$_x$ conversions of NACs A, B and C



Low Cost Motorcycle Catalysts for the Indian Market

The Platinum Group Metal (PGM) content of catalyst formulations contributes significantly to the overall cost of catalytic converters for motorcycles. The challenge for the catalyst industry is to reduce the PGM content while maintaining high pollutant conversions and durability demanded by motorcycle manufacturers and legislation. In a paper presented at SIAT 2003, Johnson Matthey demonstrated low PGM catalysts and novel catalyst substrates capable of cutting convertor costs for Indian motorcycles.



New, highly durable, low PGM motorcycle catalyst formulations for the Indian 2-wheeler market

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Joanna Sheppard,
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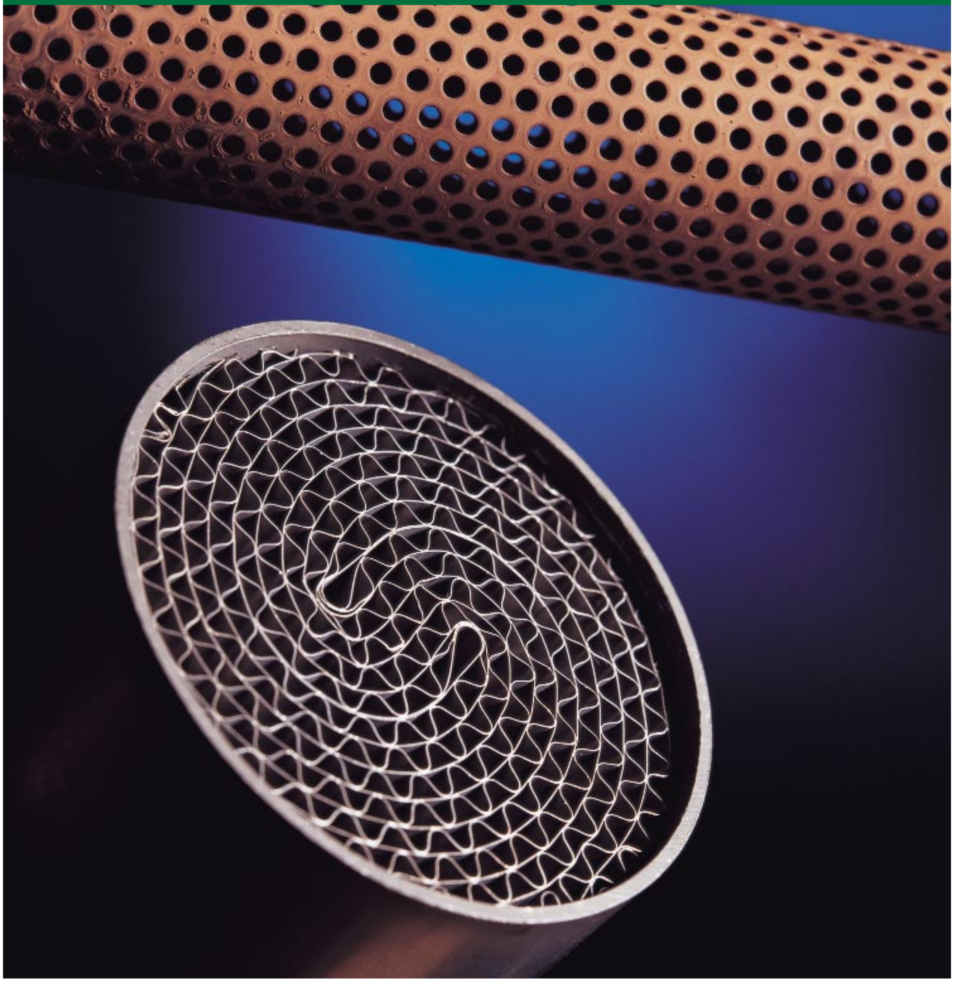
ARAI and SIAT 2003

SAE paper 2003-26-0003

Johnson Matthey

The enclosed technical paper was presented at SIAT 2003. It demonstrates that low PGM catalysts and novel catalyst substrates are capable of cutting convertor costs for Indian motorcycles.

Figure 1: Coated tube (above) and flow-through monolith (below) motorcycle catalysts



The Indian motorcycle market exceeds 4 million units a year. Traditionally, low cost carburettor-powered 2-stroke (2S) engines were dominant but consumers now favour 4-stroke (4S) engines offering better performance and fuel economy, as well as lower noise and emissions. While 2S engines require catalytic converters and carburettor tuning adjustments to meet current emissions legislation, 4S engines do not need catalysts. However, with further reductions in the legislated emissions expected in 2005, the industry anticipates catalyst use for 4S engines. Consequently, whether for 2S or 4S engines, motorcycle manufacturers are greatly concerned with the performance offered by the latest catalyst technology and the resulting cost of emissions management.

Based on a greater understanding of the chemical processes specific to motorcycle pollutant conversion, Johnson Matthey has developed a new generation of highly durable catalyst formulations. The effect of these advanced catalysts on transient conversion efficiency has been investigated for Indian motorcycles, using both conventional flow-through (FT) metallic monoliths and low cost coated tubes (CT).

Testing

To demonstrate durability, catalysts were tested fresh and aged. For 4S applications, a lean spike ageing cycle was used, while the 2S ageing was performed on a 250cc 2S bench engine. Correlation exercises with road aged catalysts confirm that the ageing protocols effectively simulate up to 30,000km of road use.

The Indian emissions limits are summarised in Table 1. The limits effectively require that catalysts meet a combined Durability Factor (DF) and Conformity of Production (CoP) limit when fresh and the CoP limit alone when aged. The CoP limit takes into account any variability of emissions between engines.

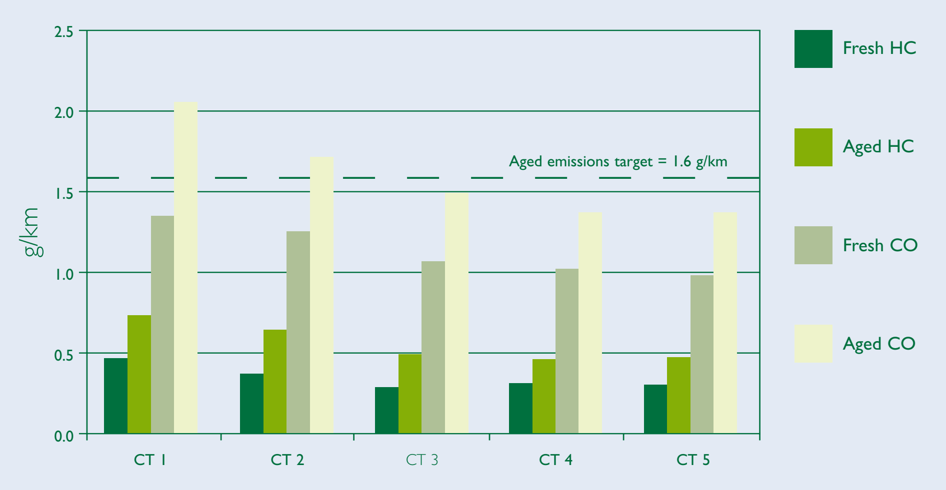
Table 1: Indian emissions targets, tested on the Indian Drive Cycle (g/km)

	$HC+NO_x$	CO
Legislative Limit 2000	2.00	2.00
Including 20% CoP	1.60	1.60
Including 20% DF	1.28	1.28

Coated tubes on the 4-stroke motorcycle

To demonstrate the effect of platinum loading on performance, tubes were coated with the same amount of rhodium and increasing amounts of platinum (see enclosed technical paper). The engine-out hydrocarbon (HC) emissions were already inside the emissions targets, which focused catalyst performance on carbon monoxide (CO) control. Fresh-coated tubes were required to meet the combined DF and CoP emissions limits, representing a mimimum of 55% CO conversion. With ageing to simulate catalyst deterioration, the emissions target reverted to the CoP limit, representing a 45% CO conversion. Coated tubes CT3, CT4 and CT5 met the aged CO conversion target but the ultra-low loaded CT1 and CT2 did not, illustrating the boundaries of PGM thrifting (Figure 2).

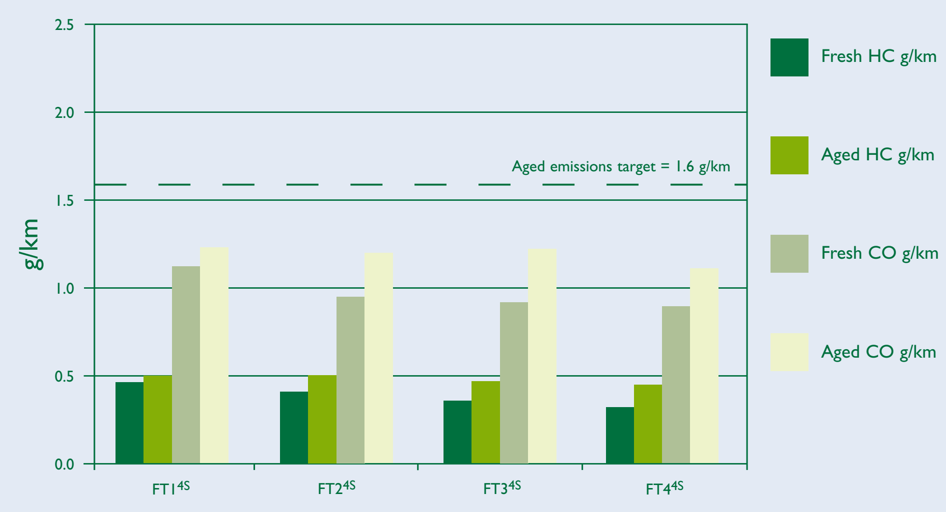
Figure 2: CO and HC emissions over coated tube catalysts on a 4S motorcycle



Flow-through converters on the 4-stroke motorcycle

The same set of experiments were repeated for flow-through converters with similar results, as illustrated in Figure 3. The catalysts met the aged CO conversion target while the baseline HC emissions were already inside the emissions targets. The small change in activity between fresh and aged catalysts demonstrates the exceptionally high durability of the washcoat formulation.

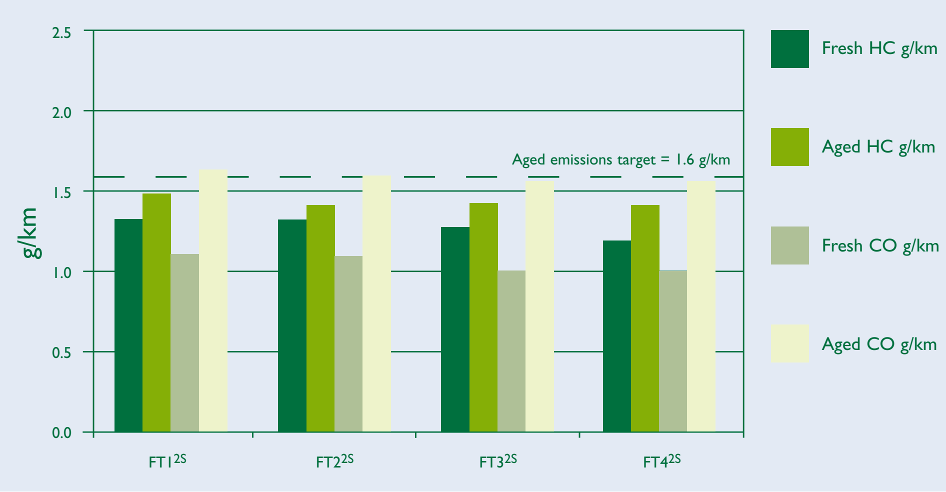
Figure 3: CO and HC emissions over flow-through catalysts on a 4S motorcycle



Flow-through converters on the 2-stroke scooter

Figure 4 summarises the pollutant conversions achieved with fresh and aged converters tested on a 2S scooter. The aged vehicle emissions were required to be below 1.6 g/km to meet the CoP target, representing an HC and CO conversion of over 40%. All the formulations achieved the aged HC conversion target and only the formulation with the lowest Pt loading, FT1, failed to achieve the aged CO conversion target. As with the 4S motorcycle catalysts, it was the durability of the washcoat formulation which allowed significantly less PGM to be used.

Figure 4: CO and HC emissions over flow-through catalysts on a 2S scooter



Conclusions

The results presented demonstrate the high performance achievable at low PGM loadings when using the latest thermally durable formulations. Both conventional flow-through metallic monolith and low cost coated tubes gave very high pollutant conversions with the required durability. As a catalyst support, the tube is both low cost and versatile as it offers sound attenuation and easy integration within a 4S engine exhaust. Excellent washcoat adhesion and a breakthrough in coating technology have helped ensure that neither catalyst activity nor durability are impaired by the manufacturing processes needed to incorporate the coated tube into the motorcycle silencer.

NO_x and PM Control Using Retrofit EGR & CRT®

Introduction

The development of emissions control systems for Heavy Duty Diesel Engines is being driven by both local and national regulations. These regulations share the common goal of cutting particulate matter (PM) and nitrogen oxide (NO_x) emissions, with the former focused on in-service vehicles and the latter on new engines under development. The need for NO_x reduction has focused attention on Exhaust Gas Recirculation (EGR) as an emissions management tool. This article summarises testing work, reported at the SAE World Congress, on combined EGR and Continuously Regenerating Trap (CRT®) technology for retrofitting to in-service vehicles. The results demonstrate 40-60% NO_x reduction combined with more than 90% PM reduction, confirming the effectiveness of combined EGR and CRT for both the North American and European markets.

Background

A growing number of cities around the world now have their own unique environmental regulations targetting lower emissions from buses and trucks. These local regulations have tended to focus on particulate matter (PM), encouraging vehicle operators to fit Diesel Particulate Filter (DPF) systems like the Continuously Regenerating Trap (CRT®). However, continued air quality concerns over nitrogen oxides (NO_x) have provided impetus for the development and testing of fuel additives and exhaust aftertreatment for NO_x reduction. One of the promising approaches to come to market has been retrofit technology combining EGR for NO_x control with a CRT filter system for PM control. This 'EGRT' technology is consistent with approaches engine manufacturers are pursuing to meet Euro 4 and US 2007 regulations.

System Description

The EGR system tested used an electronically controlled EGR throttle value to take a portion of exhaust gas for recirculation. This configuration was a low pressure loop (LPL) set up, where the exhaust gas is extracted after passing through the DPF, cooled via a heat exchanger and then reintroduced between the intake air filter and the turbo compressor using the throttle valve. The LPL set up is easier to retrofit than alternative high pressure loop (HPL) configurations, which take exhaust gas upstream of the turbo charger and route it back into the intake manifold. Another advantage of the LPL system is that the filtering of the exhaust prior to recirculation reduces the risk of PM-induced engine wear.

Engine-out NO_x emissions are a function of in-cylinder combustion temperatures. EGR trims NO_x by lowering these temperatures through reducing oxygen concentration in the combustion mixture and by adding heat adsorbing combustion products, like carbon dioxide and water. The more exhaust gas recirculated the greater the NO_x reduction. The Electric Control Unit of the EGRT system uses a map or look-up table to control the EGR rate at different speed and load conditions. This map is developed on an engine-by-engine basis by testing on an engine dynamometer with the EGRT installed. For this type of system, the NO_x reduction from the EGR varies between 20 and 70%, depending on engine speed and load.

The addition of the CRT impacts on the application of EGR. The depleted oxygen content of recirculated exhaust gas causes more incomplete combustion of fuel components and therefore higher PM emissions. The combined increase in PM and decrease in NO_x changes the engine out NO_x/PM ratio, as illustrated in Figure 3. The CRT utilises NO_2, oxidized from a portion of the engine-out NO_x, to combust soot accumulating on the filter. Therefore, a limiting NO_x/PM (or NO_x/Soot) ratio exists to ensure successful filter regeneration. Operation below this limit, will cause soot to build up in the filter, leading to higher back pressure and possible filter plugging. The key to the EGRT system lies in

Figure 1: EGRT Schematic

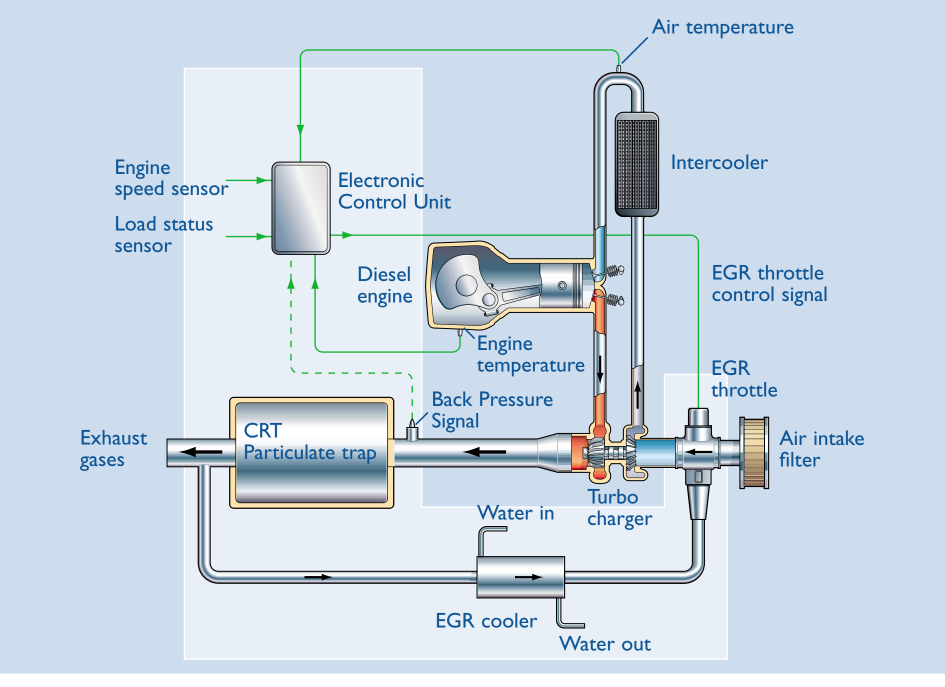
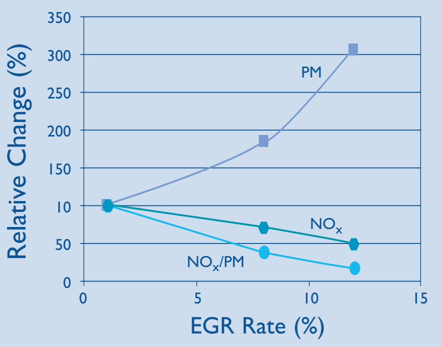


Figure 2: Engine retrofitted with EGRT

Figure 3: Emission versus EGR rate



optimising the EGR to maintain sufficient engine-out NO_X to ensure filter regeneration.

Testing Regime

To verify the effectiveness of the EGRT system for the North American market, Johnson Matthey undertook testing work on two representative engines, one from Cummins and one International, as well as vehicles powered by those engines. The vehicles were an International truck, powered by a 2000 MY International DT466 HT engine and two buses powered by 2001 Cummins ISM engines of the same power rating. The vehicles were part of a field trial, one bus being operated by AC Transit Oakland and the other by Santa Clara Valley Transit Authority (VTA). The truck was used by the California Department of Transportation (CALTRANS) for highways work. The EGR retrofit system employed was that of Swedish supplier STT and STT supplemented the US data with additional European data from testing on a Scania truck and Volvo bus.

In work conducted at Environment Canada (EC) in Ottawa, Ontario, EGR maps were developed for the Cummins and International engines. Then FTP transient tests were conducted for both engines, with and without the EGRT system. After field testing, vehicle emissions testing was conducted on a chassis dynamometer at California Air Resources Board (CARB). The vehicles were tested on three transient duty cycles; the Urban Dynamometer Driving Schedule (UDDS), the Central Business District (CBD) cycle and the New York City Bus Cycle (NYBC). The EGRT equipped Scania P94 truck was driven on the chassis dynamometer at MTC to simulate the European Steady-State Cycle (ESC), while the Volvo bus was tested on the same dynamometer, operating a simulated ECE R49 test and Braunschweig cycle.

Results

The results of the testing are summarised in Tables 1, 2 and 3. Table 1 illustrates total emissions reduction, while Table 2 illustrates NO_X reduction in grams per mile based on the bus cycles simulating city centre operation. Table 3 summarised NO_X reduction data for all of the testing conditions.

Conclusions

Commenting on the results, Johnson Matthey's Dr Sougato Chatterjee said "The results achieved were consistent across all modes of testing, confirming the NO_X reduction capability of the retrofit EGRT technology as being between 40 and 60%. These results demonstrate the emissions reduction capabilities of the retrofit EGRT system for bus and truck applications. This technology offers genuine and robust NO_X reduction and can play an important role in enabling operators to comply with the demands for NO_X reduction being made by many city authorities."

Figure 4:VTA Bus showing retrofitted EGRT

Table1: Emissions reductions with EGRT systems under FTP

	NO_X	**PM**	**HC**	**CO**	**Fuel**
International DT 466E	58.4%	91.9%	87.4%	94.6%	0%
Cummins ISM 280	46.5%	89.5%	94.8%	94.5%	1.6%

Table 2: Vehicle Testing

Vehicle	**EGR Status**	**NO_X emission (g/mile) for different test cycles**		
		NYB	**UDDS**	**CBD**
Caltrans Truck	EGR	14.54	4.1	4.42
	No EGR	29.45	9.44	11.14
VTA Bus	EGR	28.15	7.35	9.26
	No EGR	53.69	12.84	18.21

Table 3: Summary of NO_x Reductions

Engine/Vehicle	**Test**	**Test Cycle**	**Test House**	**% NO_X Reduction**
Cummins ISM	Engine	FTP transient	EC	46.5
Cummins/ VTA Bus	Vehicle	NYB	CARB	48
		UDDS		43
		CBD		49
International	Engine	FTP transient	EC	58.4
International/ CALTRANS truck	Vehicle	NYB	CARB	50
		UDDS		56
		CBD		60
Scania P94 Truck	Vehicle	Simulated ESC	MTC	54
Volvo Bus		Simulated R49		51
		Braunsweig		57

Ultra Low PGM TWC Technology for the North American Market

Three-Way Catalyst (TWC) development has, for some time, been focused on using advanced technology to deliver cost reductions for the customer. Johnson Matthey has developed a new generation of ultra low PGM catalyst technology for underbody applications. This article outlines the use of this technology, in combination with the latest low loaded close-coupled catalysts, to demonstrate sector-leading PGM thrifting.

The North American market has the most demanding set of emissions regulations for the passenger car sector. The tightening of emissions standards has placed an ever-greater burden on catalyst performance within emissions control systems. Compliance has come in part through high PGM content and larger catalyst volumes but also through calibration strategies, as well as improvements in catalyst and substrate technology. For catalyst suppliers like Johnson Matthey, the ability to deliver cost reductions through thrifting PGM and catalyst volume has been key to maintaining competitive advantage.

Issue 2,3 of Global Emissions Management included a description of the latest generation of close-coupled catalysts. The high activity and thermal durability of these catalysts have enabled exceptionally low PGM loadings to be adopted in single-catalyst systems, whilst still meeting the legislated limits of European and Mercosur markets. PGM thrifting is also being achieved for the North American market using these close-coupled catalysts, supplemented by a new generation of ultra low loaded underbody catalysts, in which the washcoat has been optimized to use only a small amount of PGM. The outcome is sector-leading low PGM loadings meeting Tier 2 and LEV 2 limits.

Light-Duty Truck Application

Figure 1 shows the exhaust system layout tested on a 2000 Model Year (MY) light-duty truck. This system had 0.8 litre (ℓ) close-coupled (CC) catalysts on each bank of the engine, utilizing 900 cpsi substrate. The catalyst technology was zone coated. The exhaust system also had 1.3 ℓ underbody (UB) catalysts on each bank of the engine, using 400 cpsi substrate. In line with Tier 2 and LEV 2 testing protocols, the catalysts were dyno-aged to 50,000-mile durability using a 4-mode ageing cycle.

Figure 2 shows the effect of PGM loading in the ultra low PGM catalyst technology for two exhaust systems. Set 1 utilized CC catalysts with a total of 1.24g of PGM in the front zones, and a total of 0.42g in the rear zones plus 0.27g on the UB catalysts. Set 2 used the same PGM loading in the CC catalysts, but used half the total PGM in the UB catalysts.

The graph on the left-hand side of Figure 2 shows the non-methane hydrocarbon (NMHC) results from the FTP test. Set 1 achieved NMHC emissions of 0.042 g/mile, while Set 2 achieved 0.043 g/mile. Both systems were well below the LEV2 NMHC standard of 0.075 g/mile. The table immediately beneath the chart separates hydrocarbon (HC) conversion efficiencies between the UB and CC catalysts. For Set 1, the zoned CC catalysts gave 96.9% HC conversion, while the UB catalysts gave 30.0% HC conversion. When the loading was reduced in the UB catalyst in Set 2, the HC conversion over these catalysts was 23.9%.

"LEV2 emission standards can be met on a light duty truck with less than 2 grams of PGM."

The right-hand side of Figure 2 shows the NO_x results from the FTP test. As with the NMHC emissions, both Set 1 and 2 were well below the LEV2 NO_x standard of 0.050 g/mile. The table immediately beneath the chart again separates the CC and UB catalyst NO_x conversions. For Set 1 the zoned CC catalysts gave 94.4% NO_x conversion, and the UB catalysts gave 81.0% NO_x conversion. In Set 2, NO_x conversion was 95.4% and 79.6% respectively. It was the high NO_x conversion from the ultra low PGM UB catalyst technology that allowed these systems to easily meet LEV2 standards. The exhaust system in Set 1 used a total PGM loading of 1.93 grams, while Set 2 used only 1.80 grams of PGM.

Figure 3 demonstrates the effect on emissions of further reductions in PGM loading in both the CC and UB catalysts. When the PGM loading of the CC catalyst was reduced (comparison of Set 2 and 3), the NMHC emissions increased from 0.043 g/mile to

Figure 1: Light-Duty Truck System Layout

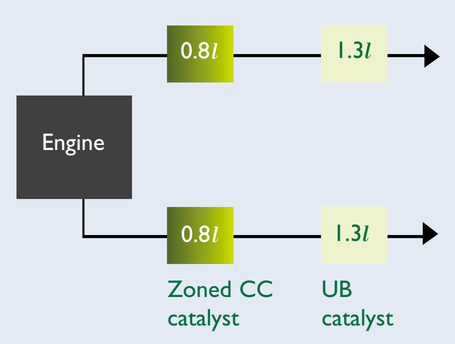
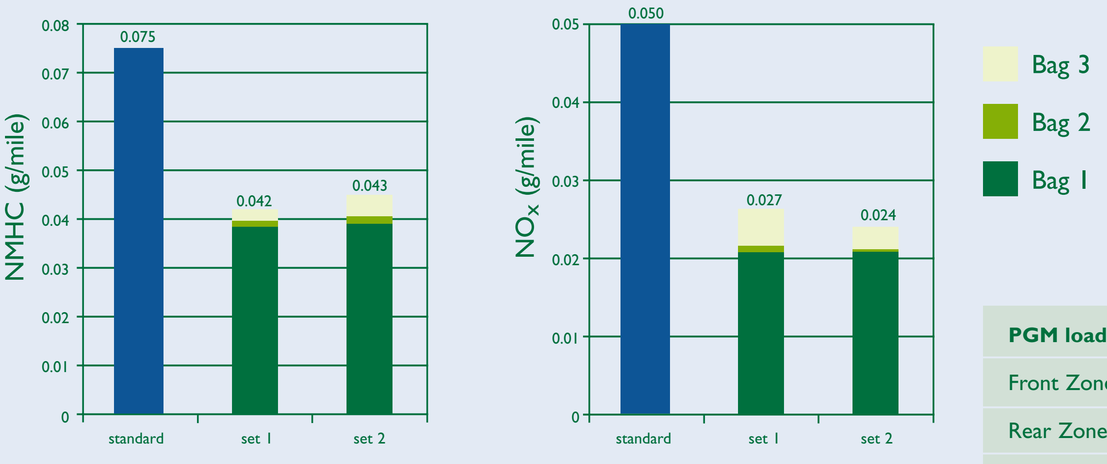


Figure 2: Effect of Underbody Catalyst PGM Loading



	set 1	set 2
CC	96.9%	96.9%
UB	30.0%	23.9%

	set 1	set 2
CC	94.4%	95.4%
UB	81.0%	79.6%

PGM loading	**set 1**	**set 2**
Front Zones	1.24g	1.24g
Rear Zones	0.42g	0.42g
UB	0.27g	0.14g
Total	**1.93g**	**1.80g**

0.072 g/mile. This was due to the lower HC conversion of the lower PGM catalyst (96.9% dropping to 92.9%). However, the HC conversion of the ultra low PGM UB catalyst technology increased from 23.9% to 43.8% when the PGM content of the CC was reduced. This increase was due to the higher pollutant concentration going into the UB catalyst of Set 3 and the capability of the ultra low PGM catalyst technology to deliver higher conversion efficiency.

Figure 3 also shows the NO_x results from the FTP test. As with the NMHC results, when the PGM loading of the close-coupled catalyst was reduced (comparison of Sets 2 and 3), the NO_x emissions increased from 0.024 g/mile to 0.057 g/mile. This was due to the loss of NO_x conversion as a result of the lower PGM loading on the CC catalyst (84.4% vs 95.4%) again offset by higher NO_x conversion from the UB catalyst (79.6% to 84.9%) based on higher pollutant concentrations entering the UB catalyst of Set 3.

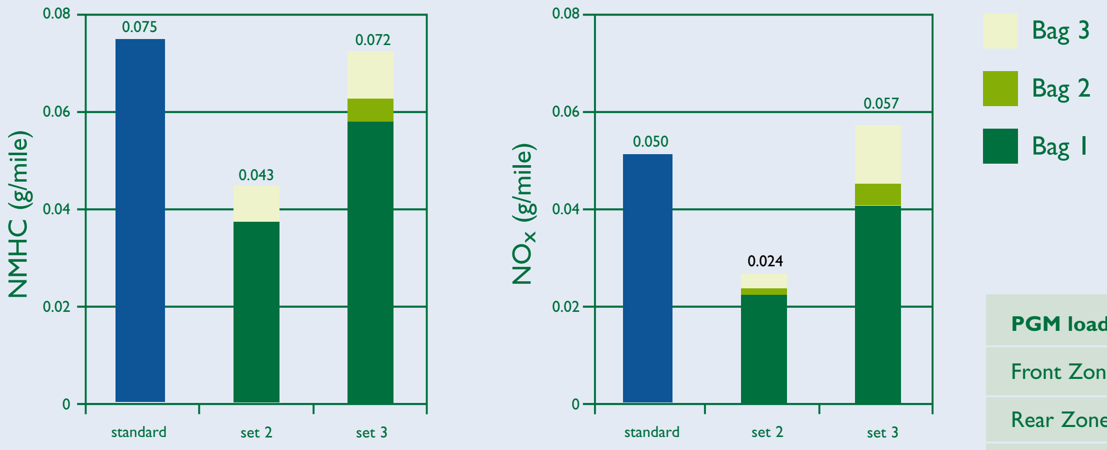
Given that the exhaust system of Set 3 was just over the NO_x standard, the results demonstrate the potential of such a low PGM catalyst system as further improvements in engine design and control ought to allow this system to achieve LEV2 emission standards.

Conclusions

The results clearly show that LEV2 emission standards can be met on a light-duty truck with less than 2g of PGM using Johnson Matthey's ultra low PGM catalyst technology. The same low loadings have been replicated for a typical passenger car application.

Commenting on the results, Johnson Matthey's North American Sales & Marketing Director Chris Bennett said "Our latest ultra low PGM loading catalyst technology is sector-leading. PGM thrifting helps our customers avoid cost fluctuations for exhaust systems caused by volatile PGM prices."

Figure 3: Effect of Close-Coupled and Underbody Catalyst Loading



	set 2	set 3
CC	96.9%	92.9%
UB	23.9%	43.8%

	set 2	set 3
CC	95.4%	84.4%
UB	79.6%	84.9%

PGM loading	**set 2**	**set 3**
Front Zones	1.24g	0.90g
Rear Zones	0.42g	0.06g
UB	0.14g	0.14g
Total	**1.80g**	**1.10g**