Emission Control Technology at Detroit

A SELECTIVE REPORT FROM THE 1998 SAE ANNUAL CONGRESS

The 1998 Detroit "Congress and Exposition" of the Society of Automotive Engineers (SAE) took place in the Cobo Center during the last week in February, with the theme "Engineering the Product Development Revolution". There were 46,100 registered attendees, with representatives from all countries concerned with the manufacture of motor vehicles and their components. In total, 1146 papers were presented, covering all the technologies associated with the industry. This review focuses on the roles that platinum group metals (PGM) play in exhaust aftertreatment, the demands of diesel engine technology and the new lean-burn gasoline engine technologies. The numbers of the relevant SAE papers are given in parentheses.

Legislative Trends

R. Becker and R. Watson (Environex) reviewed (980413) trends in emissions control, emphasising that 1997 U.S. LEV (Low Emissions Vehicles) standards already typically require more than 98 per cent reduction in hydrocarbons (HC), and 95 per cent reduction of carbon monoxide (CO) and nitrogen oxides (NOx). Future standards require even higher conversions, and the use of on-board diagnostics demands the optimisation of sophisticated engine emissions feedback control, in combination with high performance catalysts incorporating activity monitoring.

Fuel-efficient diesel engines may help towards lowering carbon dioxide (CO_2) emissions. Diesel engines operate under very lean conditions, and their low CO and HC emissions are further reduced by platinum oxidation catalysts. However, removal of particulate matter (PM) and NOx emissions is not straightforward, and Michael Walsh, consultant, reviewed (980186) how regulatory authorities are focusing on these pollutants. Current PM regulations target the mass of the particulates, but the size and numbers of PM may also be important, and future regulations could be concerned with both. Decreasing the emissions from automobiles continues, irrespective of the type of internal combustion engine, and some of the strategies for accomplishing this are described below.

Three-Way Catalysts

Renault and Johnson Matthey discussed (980936) gas flow variations across catalyst faces. Cone dimensions and inlet pipe sizes were modelled, and their effects on catalyst ageing, light-off and performance on bench engines and cars were measured. Exhaust gas maldistribution significantly affected catalyst performance. In a related paper, Eberspächer and Fachhochschule Darmstadt, considered (980424) cone geometry and the distance between two monoliths in a converter. The space between the monoliths influences flow distribution in the first and second catalysts, and a distance of about 10 mm may be optimal. W. Maus and R. Brück (Emitec) gave a paper (980414) on the catalyst in converter cones. These "conical catalysts" provide additional catalyst, and possibly allow a reduction in volume of the main catalyst. Other benefits resulting from conical catalysts should be a shortened cone length and more efficient catalyst usage by forcing gas impinging on the main catalyst into desirable flow patterns. M. Laurell, I. Gottberg and T. Idoffsson (Volvo) reported (980416) converter optimisation with three catalysts; this included modifying the gas flow distribution, the cell density and the PGM loadings.

Mounting the catalyst close to the engine reduces the warm-up time, but this location is "materials demanding" in terms of thermal durability. Corning described (980042) how the high-temperature matt deterioration experienced with oval-shaped ceramic catalysts was overcome by new designs. Emitec indicated (980420) that low thermal mass catalysts can facilitate fast warm-up, while G. Faltermeier and B. Pfalzgraf (Audi), R. Brück (Emitec) and A. Donnerstag (Volkswagen) reported (980417) some conflicts in close-coupled designs. These include mechanical deterioration due to vibration and turbulence, and good gas flow distribution to obtain maximum catalyst efficiency while maintaining engine torque and optimised warm-up times. E. Otto, F. Albrecht and J. Liebl (BMW) discussed (980418) a six cylinder engine programme which came to broadly similar conclusions.

Johnson Matthey reported (980421) progress in developing a new ultra-low emissions concept involving close-coupled three-way catalysts for NOx control, and underfloor trap technology with a novel palladium ambient-temperature CO oxidation catalyst operating under lean conditions. With this catalyst, CO oxidation has positive order kinetics in CO concentration, and a large exotherm occurs during rich start-up. Data were given for a standard 1995 model year vehicle, modified for rich start-up. This achieved emissions 50 per cent lower than the ULEV (Ultra Low Emissions Vehicles) requirement.

Honda described (980415) how ULEV emissions can be achieved with underfloor catalyst, by the optimisation of a variable valve timing and lift mechanism, a new catalyst, precise air/fuel control with a lean air/fuel ratio after starting, and exhaust components having low heat capacity. A high loading palladium catalyst facilitated light-off, and effective oxygen storage enhanced hot HC oxidation. A substrate of high cell density (600 cpsi) and low thermal mass was additionally employed.

Lean-Burn Gasoline Engines

In paper (980933) Johnson Matthey described a high temperature stable aftertreatment system for lean-burn engines. A new close-coupled fast light-off catalyst was formulated not to degrade reduction under rich conditions of stored NOx, in a new high-capacity underfloor trap.

Sulfur compounds in fuel are detrimental because they are oxidised to sulfur dioxide (SO_2) in the engine and then block NOx storage sites on the catalyst. Sakai Chemical Industry Company and Tottori University reported (980932) results for a variety of sulfur oxides (SOx) traps. These absorb SOx under lean conditions and desorb it at high temperature under rich conditions. A contribution from Next Generation Catalyst Research Institute in Japan, discussed (980930) a two-catalyst, SOx resistant system. The first catalyst is copper/zeolite which stores SOx as sulfate, so protecting the rear, platinum/gold catalyst supported on titania.

Reliable ageing cycles are important for the development of lean-NOx catalyst systems. J. M. Kisenyi (Ford) presented (980934) work by Ford and Tickford Ltd where the relationships between vehicle emissions and catalyst, aged in a high temperature dynamometer cycle, were established. The cycle had significant lean phases obtained by periodic injection of air into the exhaust of an engine running rich. Good correlation was achieved, with 75 hours of dynamometer ageing being equivalent to a distance of 80,500 km.

Diesel Aftertreatment

Oxidation and NOx Removal Catalysts

Diesel engines are very fuel-efficient under part-load/idle conditions, and the University of Central England confirmed (980192, 980193) that exhaust gas temperature might then be too low for underfloor oxidation catalysts to perform well. At higher load, temperatures are higher, resulting in good oxidation conversions. One improvement that could be made to meet more stringent emissions is to mount catalysts in a hotter location close to the engine, and in the usual underfloor position. N. E. Chemcat Corporation discussed (980931) two-catalyst systems, and the role of zeolites in platinum catalysts to enhance NOx conversions. They highlighted a need to control HC/NOx ratios for optimum performance. A. Peters (Daimler-Benz) presented a paper (980191) with Degussa on the optimisation of a two-catalyst system on an engine with common rail fuelling. Here it is possible to control the exhaust HC/NOx ratio for optimum NOx reduction, and with two catalysts it is possible, during low speeds, to have the front one operating in the NOx reduction temperature window characteristic of platinum catalysts, and to have the underfloor one operating in this temperature range at high speeds.

Optimal NOx removal can then be obtained under most operating conditions. Toyota illustrated (980195) that zeolites can absorb HC when the catalyst is cool, and enhance NOx reduction. Zeolite can convert high molecular weight soluble organic fraction (SOF) to smaller molecular fragments, so aiding their oxidative destruction; and sulfate production can be minimised by using washcoat materials having low affinity for SO_2.

Particulate Control

Sulfur is a catalyst poison, and can affect the amount of particulate present in diesel exhaust after oxidation catalyst treatment. Degussa, ICT and The Technical University Darmstadt confirmed (980196) that the SOF of diesel particulate can be reduced by a platinum oxidation catalyst at the temperatures present in automobiles, whereas at higher temperatures, around 350°C, oxidation of SO_2 to sulfur trioxide (SO_3) and hence sulfuric acid takes place. This is adsorbed on PM. As a result, at low temperatures, SOF is oxidised and PM mass is reduced, but at higher temperatures the formation of sulfate increases the observed amount of PM. They also described how PM analysis itself can influence the measured values, due to droplet formation. A related paper (980525) from the University of Minnesota and Perkins Technology Ltd came to broadly similar conclusions.

The European VERT project described (980539) a new hypothesis for diesel engine soot formation involving fuel dissociation to produce fast diffusing hydrogen which is then burned, leaving carbon in oxygen-depleted zones. A range of aftertreatment diesel particulate filters (DPFs) were tested, and their characteristics reported in combination with different hydrocarbon soluble fuel additives. These are converted to metal oxides in the engine, and appear to reduce raw emissions and to catalyse the combustion of trapped soot at moderate temperatures. Concerns include the build-up of soot during extended low speed driving and nanosized metal oxide particles possibly passing into the environment, which would not be "toxicology permissible" for many additives.

L. Montanaro and A. Negro found (980540) sodium compounds, derived from fuel additives, were the most reactive species, in potentially detrimental reactions with filter materials; and a contribution from Aristotle University, Rhône-Poulenc and Renault reported (980543) results for different filter positions on a light truck.

A well-attended paper (980189) from Johnson Matthey, HJS Fahrzeugtechnik, Corning, Fraunhofer-Institute of Toxicology and Aerosol Research, and FEV Motorentechnik described further studies on Continuously Regenerating Traps (CRTs) which can overcome some diesel particulate filter deficiencies when low sulfur fuel is used. In this system a high proportion of CO and HC (including non-regulated emissions like aldehydes) are oxidised over a platinum-based catalyst. Most HC species downstream of the CRT were too low to be measured accurately. Most of the nitric oxide in the exhaust gas is oxidised to nitrogen dioxide (NO_2) over the catalyst, and particulate emissions retained in a filter are burnt via reaction with NO_2. Because this is a relatively low temperature reaction, particulate removal from the filter takes place at all but very low temperatures. It is well established that this system dramatically reduces particulate mass emissions, so the work described focused on particle number emissions. These were recorded down to a primary diameter of 15 nm, and had been reduced by one to two orders of magnitude, and even the nanosized particles were effectively reduced.

Conclusions

Most of these papers are collected in SAE "Single Publications"; the most pertinent being: "Diesel Exhaust Aftertreatment 1998" (SP1313), "General Emissions (SP1335), "Advanced Converter Concepts for Emission Control" (SP1352) and "Catalysts Emission Control and Lean-NOx Technologies" (SP1353). Once again, the Detroit SAE Congress provided a focus for developments in emissions control technology, and it is clear that PGM-containing catalysts have a major role in achieving the emissions standards soon to be introduced.

M. V. TWIGG