

Promoting Platinum Metals by Ceria

METAL-SUPPORT INTERACTIONS IN AUTOCATALYSTS

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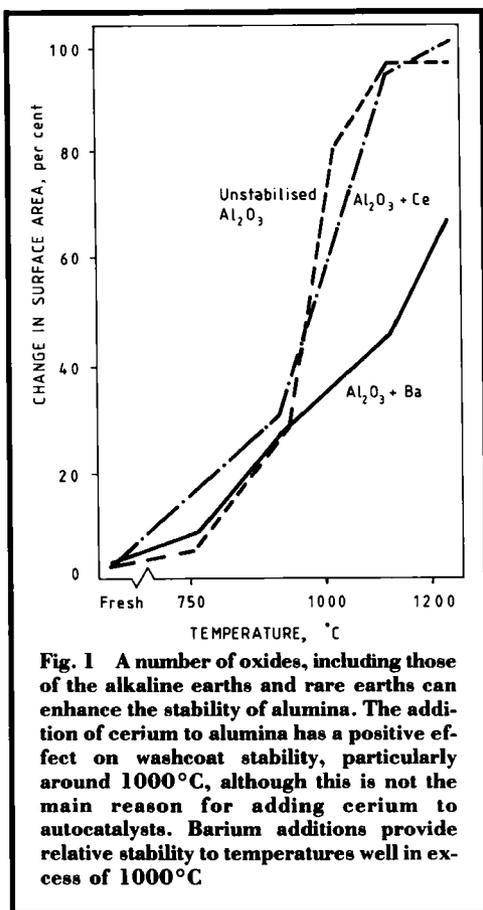
Modern autocatalysts are complex, multi-component systems which, when combined with vehicle fuel calibration systems, are able to provide the activity, selectivity and durability required to meet the exacting emissions standards now demanded. In addition to the platinum group metals, one of the major components in current three-way catalysts is ceria, whose main role was originally thought to involve oxygen storage under transient conditions. In practice, the situation is more complex, with ceria contributing to a number of catalytic functions and also interacting with the active platinum group metals.

Catalytic converters have been the universally accepted method of automobile emissions control in the U.S.A. and Japan since the mid 1970s, and more recently have been adopted in Australia. Two types of catalyst have been used. Oxidation catalysts convert unburnt hydrocarbons and carbon monoxide to carbon dioxide and water, while three-way catalysts, in addition, convert oxides of nitrogen to nitrogen (1). Catalysts can convert in excess of 90 per cent of these pollutants and, if combined with appropriate engine management systems, can meet any known existing or proposed emissions standards. Oxidation and three-way catalysts differ in formulation, the former usually containing palladium or platinum + palladium and the latter containing platinum + rhodium. Since the introduction of catalytic converters, significant advances have been made in their design with regard to activity, durability and time of response to fluctuating exhaust conditions (2, 3).

There are five major components in vehicle exhaust catalysts: the substrate, the support, stabilisers, base metal promoters and platinum group metals. The most commonly used substrate materials are multicellular ceramic monoliths which have a high open area and exert little back pressure in the exhaust system. Metallic monoliths are also used, especially in

situations where the greater open area and even lower back pressure of these systems is an advantage. The properties and uses of ceramic and metallic monoliths are reviewed in depth elsewhere (4-8) and will not be discussed further here. In order to increase the surface area of the monolith, a coating of a highly porous material, usually alumina, is applied. This is known as the washcoat. Stabilisers are often added to the washcoat to maintain the high surface area at the elevated temperatures which are encountered under operating conditions (2, 3). Promoters are included to improve the activity or selectivity of the catalyst and can have a strong influence on performance. The most widely applied promoters in three-way catalysts are nickel and cerium (9, 10). The primary catalytic components of current car exhaust catalysts are platinum group metals, which combine the benefits of high activity, particularly at low temperatures, with stability and resistance to poisoning.

Cerium, usually as its oxide ceria, is used very widely in present day three-way catalyst formulations. Initially, it was thought that the main function of this component was as an oxygen storage component (11), that is as a component which stores oxygen under lean operating conditions—thus promoting conversion of oxides of nitrogen—and releases it under



rich conditions by reaction with carbon monoxide or hydrocarbons. In practice, the role of cerium in promoting platinum metals and in particular rhodium, is much more complex than this and is the main subject of this paper.

Washcoat Stabilisation

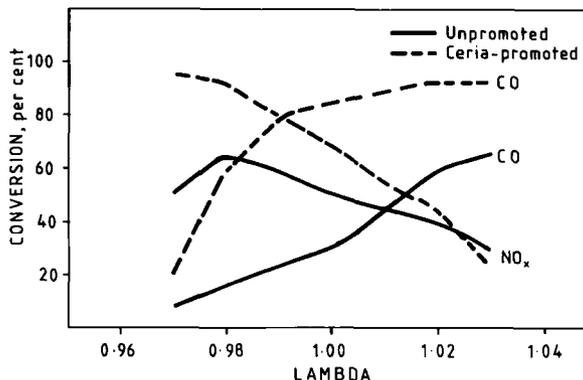
An autocatalyst washcoat comprises gamma-alumina in combination with a mixture of promoters and stabilisers. This provides a high surface area upon which to maximise the dispersion of the active noble metals. Although gamma-alumina is inherently thermally stable and only slowly converts to the delta-, theta- and alpha-phases as the temperature is raised, it is normal to add stabilisers to retard these transitions and maintain a high surface area in situations where exhaust gas temperatures can

exceed 1000°C. A number of oxides, including those of the alkaline earths and rare earths are able to enhance the stability of alumina (12). This is illustrated in Figure 1, where the stabilising effect of barium and cerium is compared with that of unstabilised alumina. Although washcoat stabilisation is not the main reason for adding cerium to autocatalysts, it is seen to have a positive effect, particularly in the region of 1000°C. Barium, however, provides relative stability to the washcoat to temperatures well in excess of 1000°C.

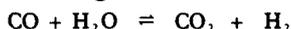
Enhancement of Rhodium Activity

Rhodium is a crucial component of three-way catalysts, particularly with regard to carbon monoxide and nitrogen oxides conversion at rich and stoichiometric air:fuel ratios. Unfortunately, rhodium is extremely sensitive to deactivation at high temperatures under the lean operating conditions which can be encountered during high speed cruising. The deactivation is thought to be due to a strong rhodium-alumina interaction, which fixes rhodium in a high oxidation state which is difficult to reduce (13). This interaction can be blocked or at least retarded by the incorporation of ceria into the catalyst, resulting in improved performance after high temperature ageing under oxidising conditions, see Figure 2. Conversion of nitrogen oxides shows improvement particularly under rich conditions, while carbon monoxide conversion is increased across the range of equivalence ratios encountered. The promotion of carbon monoxide conversion in the rich region merits particular attention, since this cannot be achieved by reaction with oxygen. Examination of a series of aged platinum + rhodium three-way catalysts, containing increasing quantities of ceria, in a simulated exhaust both with and without water, reveals the nature of the reaction which is being promoted. In the absence of water, an increase in ceria loading has no effect upon the carbon monoxide conversion achieved by the catalyst. When water is present, however, a dramatic effect is observed, with increasing ceria loading causing an increase in conversion, see Table I.

Fig. 2 The interaction between rhodium and alumina can be blocked or retarded by incorporating ceria. This gives an improved performance after high temperature ageing under oxidising conditions. The conversion of nitrogen oxides is improved, particularly under rich conditions, while carbon monoxide conversion is increased across the whole equivalence ratio range



This leads to the conclusion that ceria is promoting the water-gas shift reaction:

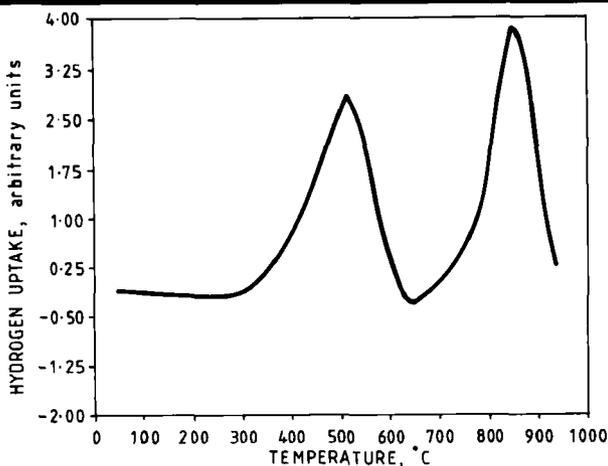


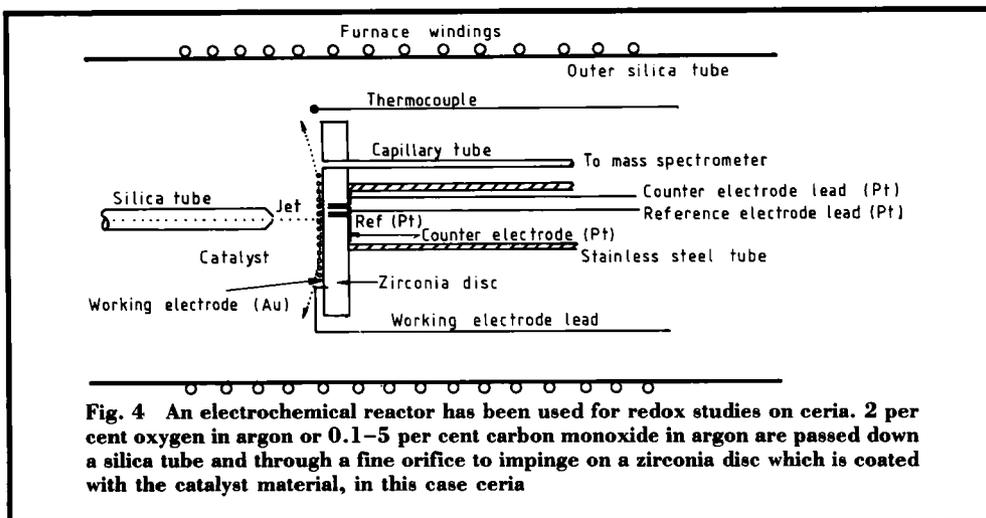
The Interaction of Platinum Group Metals with Ceria

If ceria is to be considered as an oxygen storage component then, by definition, it should be capable of being reduced and re-oxidised readily. Temperature programmed reduction (TPR) has been used to explore the reduction of ceria in hydrogen, as shown in Figure 3 where two reduction peaks are seen, this being in agreement with previous workers (14). The low temperature peak (500°C) is assigned to the reduction of a surface species;

the size of the peak appears to be dependent on preparation. Other workers have attributed the peak to the reduction of surface capping oxygen anions attached to a surface Ce^{4+} ion (15). The higher temperature peak (>800°C) corresponds to the reduction of bulk oxygen and the formation of lower oxides of cerium. For ceria to act effectively as an oxygen storage component, these reduction processes must be readily reversible. Sequential temperature programmed reduction/oxidation has therefore been used to establish the ease with which re-oxidation of ceria occurs. A sample of ceria was reduced at 700°C in a TPR apparatus and then heated in an oxygen-containing atmosphere to 980°C. During the latter process there was no oxygen

Fig. 3 The temperature programmed reduction of ceria in hydrogen shows two reduction peaks. One at 500°C is assigned to the reduction of a surface species, while the higher peak at around 800°C corresponds to the reduction of bulk oxygen and the formation of lower oxides of cerium





uptake, indicating that the lower temperature reduction process was not readily reversible in the presence of oxygen. A second sample was reduced at 980°C and subsequently treated in an oxygen-containing atmosphere. This sample did take up oxygen at about 90°C. Thus, for ceria to act as a true redox component, temperatures in excess of those encountered under most normal conditions on vehicles are required.

The reduction of ceria in a carbon monoxide atmosphere has been investigated in the electrochemical reactor shown in Figure 4. Oxygen (2 per cent) in argon, or carbon monoxide (0.1 to 5 per cent) in argon was passed through a silica tube with a fine orifice, forming a jet

which impinged on a zirconia disc coated with ceria. Two types of experiment were done, in which the working electrode was either allowed to float (potentiometric measurement) or was held at a fixed potential. Figure 5 shows the potentiometric response for ceria as a function of carbon monoxide concentration, after the gas was switched at $t=0$ from the oxygen mixture to the carbon monoxide mixture. The change in potential can be attributed to the removal of lattice oxygen from the ceria, as carbon monoxide is oxidised to carbon dioxide. If the potential applied to ceria is systematically varied in order to change the number of anion vacancies (Figure 6), the response time decreases as the electrode is made more negative and the value

Ceria loading	CO conversion with H ₂ O, per cent	CO conversion without H ₂ O, per cent
1 × Ceria	54	49
2 × Ceria	64	49
6 × Ceria	70	49

Fig. 5 The potentiometric response for ceria is shown as a function of carbon monoxide concentration at 973K after the gas was switched at $t=0$ from the oxygen mixture to the carbon monoxide mixture. The change in potential can be attributed to the removal of lattice oxygen from ceria as carbon monoxide is oxidised to carbon dioxide

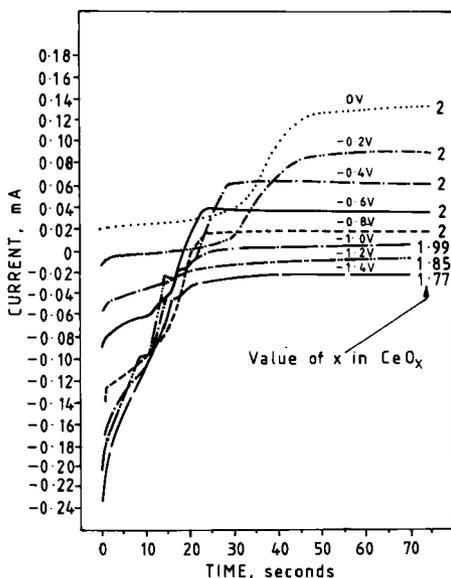
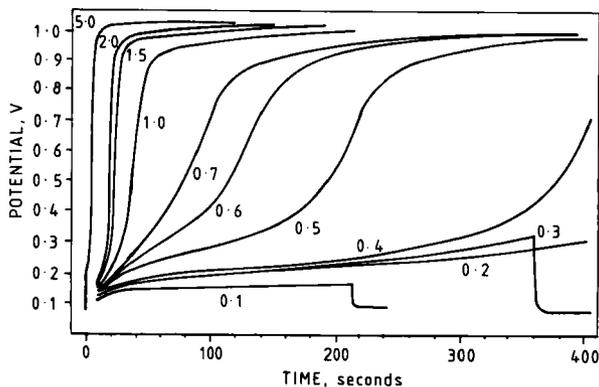


Fig. 6 If the potential applied to the ceria is systematically varied, the number of anion vacancies changes. The response time for the reaction of ceria with 1 per cent carbon monoxide at 973K decreases as the electrode is made more negative, with the consequence that the value of x in CeO_x decreases

Fig. 8 Platinum and palladium also promote the reduction of surface oxygen in ceria, and the temperatures for the surface reduction peaks are lowered. However, the peaks for the surface reductions are smaller than those for the bulk reduction

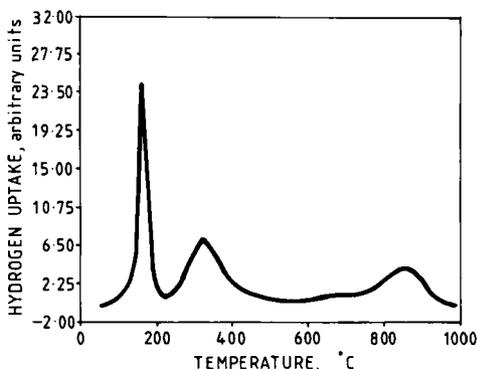
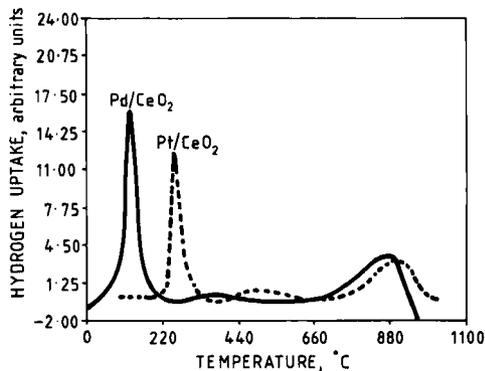


Fig. 7 The temperature programmed reduction profiles of ceria are substantially altered by the addition of platinum group metals. The addition of 1 per cent rhodium is particularly effective in promoting the reduction of surface oxygen. Rhodium itself reduces at around 150°C, and the surface reduction temperature of ceria is lowered to 350°C. The bulk reduction peak remains at around 870°C



of x in CeO_x decreases. Overall, these experiments suggest that the kinetics of carbon monoxide oxidation on ceria are slow and may be limited by the low concentration of suitable sites for carbon monoxide adsorption. As the reaction proceeds the number of sites on the surface may increase, causing an increase in the rate. This is further evidence that pure ceria may be difficult to reduce under automotive conditions.

The role of ceria becomes more apparent when it is investigated in combination with platinum group metals. In particular, the TPR profile of ceria is substantially altered (Figures 7 and 8, compared to Figure 3) and it is apparent that rhodium, platinum and palladium promote the reduction of surface oxygen. Rhodium is particularly effective in this process, as can be seen from the relative sizes of the surface and bulk reduction peaks: in the case of rhodium + ceria, the surface peaks are larger than the bulk, while for platinum + ceria or palladium + ceria the reverse is true. This may

be related to the heat of adsorption of water, which is much higher for rhodium than for platinum or palladium (16). Thus, hydrogen is dissociatively adsorbed on the platinum group metal and may react with an oxide ion in the ceria surface to form a hydroxyl group. Such a hydroxyl group would be adsorbed more strongly by rhodium than by platinum or palladium, so rhodium would more easily catalyse the formation of water, which then leaves the metal surface. As a result, oxygen vacancies are introduced into the ceria lattice at sites near noble metal crystallites.

It is particularly interesting to compare the TPR of rhodium+ceria with that of rhodium + alumina (Figure 9). In the TPR of rhodium + alumina, a single, very broad peak is observed, which corresponds to the reduction of Rh(III) to Rh(0). This suggests that the interaction between rhodium and alumina is strong, and may inhibit the redox capability of rhodium under transient autocatalyst conditions (13). In contrast, the interaction between

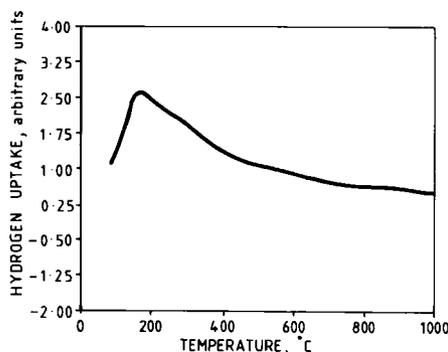


Fig. 9 The temperature programmed reduction of 1 per cent rhodium/alumina shows a single, very broad peak, which corresponds to the reduction of Rh(III) to Rh(0). This suggests that the rhodium-alumina interaction is strong, and may inhibit the redox capability of rhodium under transient autocatalyst conditions. However, the interaction between rhodium and ceria maintains the rhodium in a reducible form

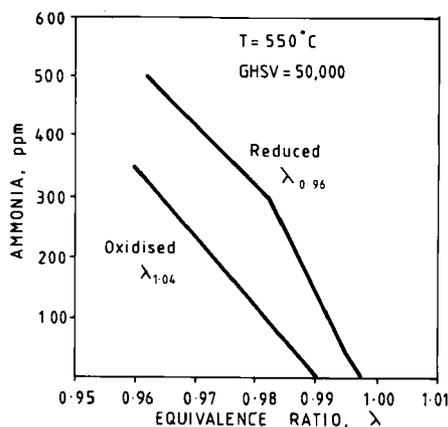


Fig. 10 Ammonia formation over Pt/Rh/CeO₂ catalysts is shown for a catalyst which had been treated under rich conditions ($\lambda = 0.96$) for 3 hours prior to testing and for the same catalyst treated under lean conditions ($\lambda = 1.04$) for 2 hours. Ammonia formation is greatest for the former catalyst. Under normal vehicle operation, rich conditions are not encountered, so ammonia formation is not a problem

rhodium and ceria maintains rhodium in a reducible form.

A further facet of the influence of ceria is revealed when the formation of ammonia over platinum + rhodium + ceria catalysts is examined. Ammonia is an undesirable product, and rhodium is used in three-way catalysts because it is able to selectively convert oxides of nitrogen to nitrogen rather than to ammonia. Ammonia formation was greater on a platinum + rhodium + ceria catalyst which had been treated under rich conditions ($\lambda = 0.96$) for 3 hours prior to testing than it was on the same catalyst which had been treated under lean conditions ($\lambda = 1.04$) for 2 hours, this being illustrated in Figure 10.

Overall, the interaction of rhodium with ceria can be rationalised by the model shown in Figure 11. The mechanism involves associative adsorption of carbon monoxide on rhodium + ceria to produce an oxygen vacancy adjacent to rhodium. The intermediate produced may be oxidised by water, forming hydrogen by the water gas shift reaction, or by nitric oxide, when it first forms N^{\cdot} and then nitrogen. Alternatively, with prolonged rich treatment, ceria might be further reduced to give, at a particular instant, vacancy-pairs adjacent to the rhodium. Simultaneous or concerted oxidation of these sites by nitric oxide and water would then provide a route for ammonia formation. Under normal vehicle operating procedures, prolonged rich conditions are not encountered and ammonia formation is not a problem.

Sulphur Storage on Three-Way Catalysts

Gasoline contains sulphur compounds, typically at concentrations between 100 and 500 ppm (17), which are oxidised during the combustion process to produce about 20 to 40 ppm of sulphur dioxide + sulphur trioxide in the exhaust gas. Thermodynamic data indicate that the mixture of sulphur dioxide and sulphur trioxide would predominate in lean and stoichiometric exhaust gases, the ratio of sulphur dioxide to sulphur trioxide depending on temperature, while hydrogen sulphide

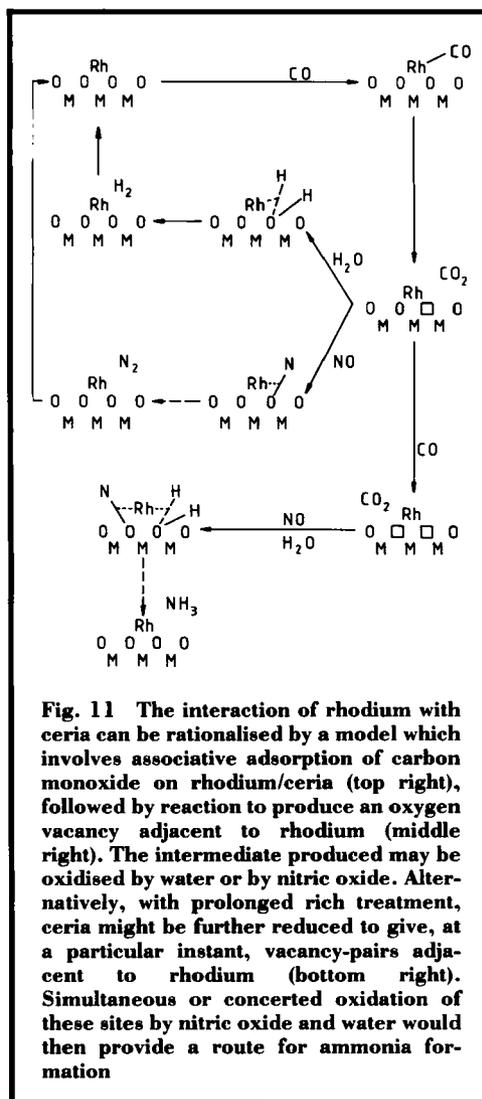


Fig. 11 The interaction of rhodium with ceria can be rationalised by a model which involves associative adsorption of carbon monoxide on rhodium/ceria (top right), followed by reaction to produce an oxygen vacancy adjacent to rhodium (middle right). The intermediate produced may be oxidised by water or by nitric oxide. Alternatively, with prolonged rich treatment, ceria might be further reduced to give, at a particular instant, vacancy-pairs adjacent to rhodium (bottom right). Simultaneous or concerted oxidation of these sites by nitric oxide and water would then provide a route for ammonia formation

would be expected to be the predominant species under rich conditions (18). Thus, it is notable that careful measurement of the exhaust gases emitted by automobiles which were not fitted with catalytic converters, or which were equipped with catalysts that did not contain noble metals, has failed to detect hydrogen sulphide (17, 19). It would appear that the reduction of sulphur dioxide and sulphur trioxide to hydrogen sulphide is, in these cases, precluded for kinetic reasons. However, hydrogen sulphide may be produced by a

Table II
Sulphur : Cerium Ratios Derived from
XPS Data Recorded on Ceria Treated with Sulphur Dioxide

Sample	Treatment	Sulphur: Cerium, $\pm 15\%$
CeO ₂	20°C, SO ₂	1.5
CeO ₂	550°C, SO ₂	15
CeO ₂	550°C, SO ₂ 900°C, N ₂	0.75

modern three-way catalyst when engine conditions become rich, following prolonged running in a lean mode. The emission of high levels of hydrogen sulphide by vehicles which undergo a "rich transient" from normal (stoichiometric or slightly lean) conditions can be understood by considering the phases which are stable at equilibrium in an oxidising/stoichiometric exhaust gas, and which would decompose readily under the influence of a decrease in the partial pressure of oxygen.

A typical modern three-way catalyst comprises platinum, rhodium, alumina and ceria, along with other additives such as stabilisers. The phases present in a catalyst in exhaust gases of various compositions, but containing sulphur dioxide, can be deduced from free energy minimisation calculations. The thermodynamic data indicate that ceria and alumina will form sulphates, which will decompose readily in a reductive atmosphere. The relative stabilities of Ce₂(SO₄)₃ and Al₂(SO₄)₃ would indicate that Ce₂(SO₄)₃ would form before, and in preference to, Al₂(SO₄)₃. Decomposition of Al₂(SO₄)₃, followed by Ce₂(SO₄)₃, would release sulphur dioxide/sulphur trioxide which might, in the presence of a platinum + rhodium catalyst, be reduced to hydrogen sulphide and thus be emitted from the exhaust, at concentrations exceeding the ambient level of sulphur in the exhaust gas. Consistent with this is the detection of traces of sulphur dioxide in the rich exhaust gas immediately following the transient. This species presumably represents the fraction of the gas

which, upon being released by the decomposing sulphates, failed to be adsorbed on a catalyst site. The level of hydrogen sulphide formed in this way, the so-called "hydrogen sulphide spike", is determined by the sulphur storage properties pertaining to the catalyst, rather than by the sulphur content of the exhaust gas, as is the case under steady-state rich conditions. Under reducing conditions, thermodynamic data indicate that platinum and rhodium may form sulphides, while cerium and aluminium would be expected to exist as the oxides. Platinum and rhodium could therefore adsorb sulphur dioxide/sulphur trioxide and react by a redox mechanism to form the sulphides, hence activating the kinetically limited reduction of sulphur dioxide to hydrogen sulphide. Production of hydrogen sulphide from the platinum group metal sulphides could then occur through reaction with hydrogen present in the gas stream or on the catalyst surface. The concentration of hydrogen sulphide produced would then be determined by the ambient concentration of reactant sulphur dioxide.

The discussion above indicates that the production of hydrogen sulphide by automotive catalysts depends on the ability of the catalyst to adsorb sulphur under lean conditions, and to release the species during rich transients, and also on the presence of platinum or rhodium which can act as favoured adsorption sites for sulphur under reducing conditions. To illustrate this model, the nature of sulphur dioxide adsorbed on the surface of the ceria has been investigated by X-ray Photoelectron

Sample	History	Binding energies, ± 0.3 eV*	
		Ce 3d _{5/2}	S 2p
CeO ₂	550°C, air	881.7	—
CeO ₂	550°C, N ₂	881.5	—
CeO ₂	20°C, SO ₂	881.6	168.0
CeO ₂	550°C, SO ₂	882.8	168.8
CeO ₂	550°C, SO ₂ 900°C, N ₂	881.3	168.0
Ce(NO ₃) ₃ ·6H ₂ O	—	883.3	—

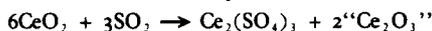
*Referred to C 1s at 284.6 eV

Spectroscopy (XPS). Samples of ceria were treated with 1 per cent sulphur dioxide in nitrogen at ambient, or at 550°C, before being cooled under nitrogen to ambient temperature. Other samples were treated with sulphur dioxide at 550°C and nitrogen at 900°C. XPS indicated that the adsorption of sulphur dioxide was greater at 550°C than ambient, see Table II. Measurements of the quantity of sulphur dioxide adsorbed by ceria under similar conditions, using gas chromatography, were consistent with these data. An examination of the oxidation states of sulphur and cerium was achieved by use of the Ce 3d_{5/2} and S 2p binding energies, as given in Table III. A sample treated with sulphur dioxide at room temperature gave a S2p binding energy which was lower than that expected (20) for S(VI) (168.5–168.9eV) and could therefore be attributed to S(IV) (166.5–167.9eV) associated with a highly charged species such as Ce(III) or Ce(IV). The Ce 3d binding energy was similar to that of ceria. Thus, sulphur dioxide is adsorbed by ceria to form a Ce(IV) sulphite at low temperature. An examination of the surface of ceria heated at 550°C in 1 per cent sulphur dioxide/nitrogen gave different results. The sulphur displayed a binding energy of 168.8eV (Table III) attributed to S(VI). A binding

energy of 882.8eV characterised the Ce 3d peak, and indicated the reduction of some surface cerium sites to Ce(III). There appears to be little data available from XPS studies of reduced ceria compounds, but the data in Table III from cerous nitrate concur with our assignment. The data therefore suggest that under the influence of heat, Ce(IV) oxide participates in a redox reaction with sulphur dioxide to form a Ce(III) sulphate, and this presumably results in the much higher sulphur:cerium ratio for the sample heated to 550°C when compared with the material prepared at room temperature. The possibility of ceria being irreversibly reduced by heating to 550°C in nitrogen in the absence of sulphur dioxide may be discounted since XPS spectra from ceria treated in this way were characteristic of Ce(IV).

Ceria was also exposed to sulphur dioxide/nitrogen at 550°C, and then heated to 900°C in nitrogen. Desorption of sulphur dioxide was detected by gas chromatography, and the sulphur:cerium ratio detected by XPS indicated that the quantity of sulphur bound to the surface was smaller than that detected in the sample heated at 550°C in sulphur dioxide, and cooled to room temperature. Furthermore, the binding energy associated with the Ce 3d peak was 881.3eV, indicating the surface to be

cerium as Ce(IV). Also, the S 2p binding energy of 168eV resembled that recorded from the sample treated with sulphur dioxide at room temperature and assigned to S(IV). Thus, the nature of the interactions between sulphur dioxide and ceria appears to depend upon temperature. At room temperature, sulphur dioxide chemisorbs onto the surface of ceria to form a sulphite, while exposure to sulphur dioxide at higher temperature leads to a redox reaction written formally as:



where "Ce₂O₃" represents reduced cerium sites in the cerium host structure. Heating this product to 900°C in nitrogen apparently induces decomposition by the reverse reaction. Trace quantities of sulphur remain in the product, and the low S 2p binding energy may indicate that the chemisorbed sulphite species is an intermediate in the decomposition process. This examination of ceria was supplemented by similar studies of metallised monolithic catalysts and catalyst washcoats. The results supported the proposed mechanism of sulphur storage by ceria-containing catalysts, in which the reduction of ceria and sulphur dioxide adsorption are intimately related.

The relationship between sulphur-storage, particularly by cerium, and hydrogen sulphide emissions was illustrated further during an investigation of the effect of ageing and poisoning of catalysts on hydrogen sulphide emissions. It has been reported that the tendency of catalysts to generate hydrogen sulphide decreases upon engine-ageing. Such catalysts have been subjected to high temperatures and possess surfaces which are coated with poisons such as phosphorus, zinc, and lead (21). It is possible that the reduced tendency towards hydrogen sulphide emissions from aged catalysts is due entirely to the effects of thermal ageing, which might include sintering of the platinum group metals, or reaction of the platinum group metals with the support. Indeed, a comparison of sulphur storage on fresh and thermally-aged catalysts confirmed that less sulphur dioxide was adsorbed by aged materials. However, a catalyst which had been doped with

phosphorus, as an example of a typical poison, showed an even more marked reluctance to adsorb sulphur dioxide, in both fresh and aged conditions. Thermodynamic calculations and experimental investigations, which will be reported in detail elsewhere, revealed that the unusually high stability of CePO₄ and AlPO₄, when compared with the oxides and sulphates, precludes the storage of sulphur. Thus, the poisons on the catalyst surface ensure that prolonged running under lean conditions does not result in sulphur storage, and therefore rich transients fail to generate spikes of hydrogen sulphide. By suitable catalyst design, it has been found that hydrogen sulphide emissions from high ceria-containing three-way catalysts can be minimised.

Conclusions

The main active components in three-way autocatalysts are platinum and rhodium, although other additives including ceria, also play a major role. Ceria contributes to alumina stabilisation, maintains rhodium in a form which is responsive to transients and promotes the water gas shift reaction under rich conditions. Ceria can promote ammonia formation, although under conditions unlikely to be encountered on a motor vehicle, and can also contribute to sulphur storage on the catalyst with resultant hydrogen sulphide emissions under rich conditions. A model for the interaction of rhodium with ceria has been proposed and the mechanism for sulphur storage on ceria-containing catalysts has been elucidated. Sulphur storage can be ameliorated by appropriate catalyst design and this will be the subject of a future publication. Overall, ceria is an important component of three-way catalysts and its full contribution to performance is only now becoming understood.

Acknowledgements

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Hydrogen in Amorphous Palladium Alloys

Substantial capacities for absorption of hydrogen by palladium and many palladium alloys, combined with high internal rates of hydrogen permeation, continue to provide attractive backgrounds for experimental study.

An additional valuable property is a retention of ductility on hydrogen absorption, which contrasts with undesirable embrittling effects produced by hydrogen in many metallic and also amorphous materials. Altogether these factors have latterly encouraged substantial research into absorption of hydrogen by glassy palladium-silicon alloys.

Two recent papers in *J. Less-Common Met.*, 1988, **138**, (2), 323-336 and 337-348 by A. Magnouche, R. Fromageau and J. Hillairet, and by R. Fromageau, A. Magnouche, G. Brebec and J. Hillairet, respectively, report a substantial body of further information concerning hydrogen in Pd₈₆Si₁₄, Pd₈₂Si₁₈ and Pd₈₀Si₂₀ amorphous alloys. The first concerns derivation of p-c-T relationships, at pressures up to 12 MPa and temperatures up to 200°C, and derived thermodynamic parameters. In the second paper ductile characteristics have allowed electrical resistivity to be utilised for studying the kinetics of hydrogen absorption and desorption, and the derivation of hydrogen mobilities. Indications of hydrogen diffusion coefficient increases with increasing hydrogen content have been interpreted as substantiating

conclusions from the p-c-T relationships of differing types of interstitial hydrogen sites in the glassy structures, and of mutual repulsions of interstitial hydrogens.

F.A.L.

A Catalytic Reaction Guide

The economics of a chemical process and the quality of the product depend to a significant extent on the use of the best catalyst for the purpose. To help industrial users identify the most appropriate catalyst for over sixty different processes, Johnson Matthey have recently prepared a guide which will contribute to the more effective use of platinum group metal catalysts. When a pointer on the slide chart is moved to indicate the desired product or reactant, the recommended heterogeneous or homogeneous catalyst and the process conditions are displayed; brief comments are also given.

The Catalytic Reaction Guide is now available in English, French and German, and may be obtained by writing to the Johnson Matthey office at Orchard Road, Royston, England; Paris, France; or Sulzbach, West Germany.